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TERRESTRIAL ENVIRONMENT (CLIMATIC) CRITERIA GUIDELINES FOR USE IN SPACE VEHICLE DEVELOPMENT, 1964 REVISION

by GLENN E. DANIELS, Editor
Aero-Astrodynamics Laboratory

NASA

*George C. Marshall
Space Flight Center,
Huntsville, Alabama*

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ABSTRACT

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This document provides guidelines on probable climatic extremes and probabilities-of-occurrence of terrestrial environmental data specifically for space vehicle and associated equipment development. The geographic areas encompassed are the Atlantic Missile Range (Cape Kennedy, Florida); Huntsville, Alabama; New Orleans, Louisiana; the Pacific Missile Range (Point Mugu, California); Sacramento, California; Wallops Test Range, (Wallops Island, Virginia); White Sands Missile Range, New Mexico; and intermediate transportation areas. Therefore, this document omits climatic extremes for world-wide operational conditions. This is consistent with the existing philosophy regarding the employment of large space vehicles, since launching and test areas are relatively restricted due to the availability of facilities and real estate.

This document presents the latest available information on probable climatic extremes, and supersedes previous information presented in MTP-AERO-63-8 (Ref. 1). Where differences exist between this document and MTP-AERO-63-8, the data presented herein shall be employed. The information in this document is recommended for employment in the development of space vehicles and associated equipment, unless otherwise stated in contract work specifications.

author

George C. Marshall Space Flight Center

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Terrestrial Environment (Climatic) Criteria Guidelines for use in Space Vehicle Development, 1964 Revision

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Glenn E. Daniels, Editor

Terrestrial Environment Group
Aero-Astrophysics Office
Aero-Astrodynamics Laboratory

TABLE OF CONTENTS

TABLE OF CONTENTS (Cont'd)

TABLE OF CONTENTS (Cont'd)

LIST OF ILLUSTRATIONS

LIST OF TABLES

LIST OF TABLES (Cont'd)

LIST OF TABLES (Cont'd)

LIST OF TABLES (Cont'd)

LIST OF TABLES (Cont'd)

NASA-GEORGE C. MARSHALL SPACE FLIGHT CENTER

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TERRESTRIAL ENVIRONMENT (CLIMATIC) CRITERIA GUIDELINES FOR USE IN SPACE VEHICLE DEVELOPMENT, 1964 REVISION

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SUMMARY

This document provides guidelines on probable climatic extremes and probabilities-of-occurrence of terrestrial environment data speeifically applicable for NASA space vehicles and associated equipment development. The geographic areas encompassed are the Atlantic Missile Range (Cape Kennedy, Florida); Huntsville, Alabama; New Orleans, Louisiana; the Pacific Missile Range (Point Mugu, California); Sacramento, California; Wallops Test Range (Wallops Island, Virginia); White Sands Missile Range, New Mexico; and intermediate transportation areas. Therefore, this document omits climatic extremes for worldwide operational conditions. This is consistent with the existing philosophy regarding the employment of large space vehicles, since launching and test areas are relatively restricted due to the availability of facilities and real estate.

This report establishes design guideline values for the following environmental parameters: (1) Temperature, (2) humidity, (3) precipitation, (4) winds, (5) pressure, (6) density, (7) electricity (atmospheric), and (8) composition of atmosphere. Data are presented for various percentiles and discussions of the data relative to interpretation as design guidelines are also presented. Additional information on the different parameters may be located in the numerous references cited in the text.

FOREWORD

For climatic extremes, there is no known physical specific upper or lower bound, except for certain conditions; that is, for wind speed there does exist a strict physical lower bound of zero. Therefore, for any observed extreme condition there is a probability of its being exceeded. Consequently, climatic extremes for design must be accepted with the knowledge there is some risk of the values being exceeded.

With regard to the subject of ground and in-flight wind, shear, and turbulence, it is understood that the launch vehicle will not be designed for launch and flight in severe weather conditions; that is, hurricanes, thunderstorms, and squalls. The design wind conditions are presented for various percentiles based on available data samples. Caution should be exercised in the interpretation of these percentiles in vehicle design to ensure consistency with physical reality.

Space and planetary environment criteria guideline documents are currently being prepared. Specific space vehicle natural environmental design criteria are specified in the appropriate organizational space vehicle design ground rules and design criteria data documentation.

It is recognized that considerably more information is available, but not in final form, on some of the topics in this document, viz., surface and in-flight winds. It is therefore recommended that users of this document concerned with design quantities for which data are not provided, or on which the data are inadequate for the problem, submit a request to the Aero-Astrophysics Office, Aero-Astrodynamics Laboratory, Marshall Space Flight Center, for the required information. An effort will be made to provide the required data or interpretation of these data, in a suitable form, for the design problem as defined with respect to approved NASA programs, through the appropriate organizational channels.

This document is a revision and should be used in lieu of the data presented in MTP-AERO-63-8 (Ref. 1). Where differences exist between this document and MTP-AERO-63-8, the data presented herein shall be employed. The information in this document is recommended for employment in the development of space vehicles and associated equipment, unless otherwise stated in contract work specifications.

SECTION I. INTRODUCTION

1.1 General

A knowledge of earth atmosphere environmental parameters is necessary for the establishment of design requirements for space vehicles and associated equipment. Such data are required to define the design condition for fabrication, storage, transportation, test, preflight, and in-flight design conditions and should be considered for both the whole system and the components and parts which make up the system. The purpose of this document is to provide guideline data on natural environmental conditions for the various major geographic locations which are applicable to the design of space vehicles and associated equipment for the National Aeronautics and Space Administration. The publication MIL-STD-210A (ref. 2) and U. S. Standard Atmosphere, 1962 (ref. 3), are suggested for use as sources of data for geographic areas not given in this document.

Good engineering judgment must be exercised in the application of the earth's atmospheric data contained in this document to space vehicle design analysis. Considerations must be given to the overall vehicle mission and performance requirements. Knowledge still is lacking on the relationships between some of the atmospheric variates which are required as inputs to the design of space vehicles. Also, interrelationships between vehicle control and structural parameters and atmospheric variables cannot always be clearly defined.

It is neither economically nor technically feasible to design space vehicles to withstand all atmospheric extremes. For this reason, consideration should be given to protection of the space vehicles from some extremes by use of support equipment, and by using specialized forecast personnel to advise of the occurrence of critical environmental conditions. The services of specialized forecast personnel may be very economical in comparison to more expensive designing which would be necessary to cope with all possibilities.

This document does not specify how the designer should employ the data in regard to a specific space vehicle design. Such specifications may be established only through analysis and study of a particular design problem. Although of operational significance, descriptions of some atmospheric conditions, i.e., cloud cover, visibility, etc., have been omitted since they are not of concern for structural and control system design. Reference 69 contains an analysis of Cape Kennedy cloud cover data.

Induced environments (vehicle caused) may be more critical than natural environments for certain vehicle design problems. Induced environments are considered in other criteria documents.

1.2 Geographic Areas Covered (Figure 1.1).

a. Huntsville, Alabama.

b. River transportation between Huntsville, Alabama (via Tennessee, Ohio, and Mississippi Rivers) and New Orleans, Louisiana.

c. New Orleans, Louisiana; Mississippi Test Operations, Mississippi; Houston, Texas, and transportation zones between these locations.

d. Gulf transportation between New Orleans, Louisiana (via Gulf of Mexico and up east coast of Florida) and Cape Kennedy, Florida.

e. Panama Canal transportation between New Orleans, Louisiana (via Gulf of Mexico to Panama Canal, through the Panama Canal up west coast of Mexico and California), and Point Mugu, California.

f. Atlantic Missile Range (AMR), Cape Kennedy, Florida.

g. Pacific Missile Range (PMR), Point Mugu, California.

h. Sacramento, California.

i. Wallops Test Range, Wallops Island, Virginia.

j. West coast transportation between Los Angeles, California and Sacramento, California.

k. White Sands Missile Range, New Mexico.

1.3 Units of Conversion

Numerical values in this document are given in the International System of Units (ref. 10). The values in parentheses are equivalent U. S. Customary Units.* The metric and U. S. Customary Units employed in this report are those normally used for measuring and reporting atmospheric data.

By definition, the following fundamental conversion factors are exact (ref. 70):

Type	U. S. Customary Units	Metric
Length	1 U. S. yard (yd)	0.9144 meter (m)
Mass	1 avoirdupoid pound (lb)	453.59237 gram (g)
Time	1 second (sec)	1 second (sec)
Temperature	1 degree Rankine (°R)	1.8 degree Kelvin (°K)
Electric current	1 ampere (A)	1 ampere (A)
Light intensity	1 candela (cd)	1 candela (cd)

To aid in conversion of units given in this document, conversion factors based on the above fundamental conversion factors are given in Table 1.1. Geometric altitude as employed herein is with reference to mean sea level (MSL).

1.4 Definition of Percentiles

The values of the data given, corresponding to the cumulative percentage frequencies are called percentiles.

The relation between percentiles and probability follows immediately: Given that the 90th percentile of the wind component is, say, 60 m/sec means that there is a probability of 0.90 that this value of the wind component will not be exceeded, and there is probability of 0.10 that it will be exceeded for the set of data from which the percentile was computed. Stated in another way: There is a 90% chance that the given wind component will not be exceeded or there is a 10% chance that it will be exceeded. If one considers the 10th and 90th percentile for the wind components, it is clear that 80% of the wind components occur within the 10-90 percentile range.

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* English Units adopted for use by the United States of America

TABLE 1.1 CONVERSION OF UNITS

TYPE OF DATA	METRIC		U.S. CUSTOMARY		CONVERSION
	UNIT	ABBREVIATION	UNIT	ABBREVIATION	
RADIATION	langley per minute	ly min^{-1}	kilojoule per square meter per second	kJ $m^{-2}sec^{-1}$	1 ly min^{-1} = 0.6973 kJ $m^{-2}sec^{-1}$ 1 kJ $m^{-2}sec^{-1}$ = 1.434 ly min^{-1}
Solar Intensity	langley to gram-calorie per square centimeter	ly to g-cal cm^{-2}			1 ly = 1 g-cal
	langley	ly	watt per square foot	watt ft^{-2}	1 ly = 64.82 watt ft^{-2} 1 watt ft^{-2} = 0.01542 ly
	langley	ly	watt per square meter	watt m^{-2}	1 ly = 697.7 watt m^{-2} 1 watt m^{-2} = 0.001433 ly
	gram-calorie per square centimeter(per minute)	g-cal $cm^{-2}(min^{-1})$	British thermal unit per square foot(per minute)	B.T.U.ft^{-2} (min^{-1})	1 g-cal $cm^{-2}(min^{-1})$ = 3.687 B.T.U.$ft^{-2}(min^{-1})$
Solar Insolation	gram-calorie per square centimeter per minute	g-cal cm^{-2} min^{-1}	British thermal unit per square foot per hour	B.T.U.$ft^{-2}hr^{-1}$	1 g-cal $cm^{-2}min^{-1}$ = 221.2 B.T.U.ft^{-2} hr^{-1} 1 B.T.U.$ft^{-2}hr^{-1}$ = 0.004521 ly min^{-1}
TEMPERATURE Ambient Temperature	degree Celsius	°C	degree Fahrenheit	°F	°C = 5/9(°F-32) °F = 9/5 °C+32
Temperature Change	degree Celsius or degree Kelvin	°C or °K	degree Fahrenheit	°F	°C or °K = 9/5 temp. change °F °F 5/9 temp. change °C or °K
WATER VAPOR Vapor Concentration (Absolute Humidity)	gram per cubic meter	g m^{-3}	grain per cubic foot	gr ft^{-3}	1 gm^{-3} = 0.4370 gr ft^{-3} 1 gr ft^{-3} = 2.288 g m^{-3}
PRECIPITATION(SNOW) Unit Depth	kilogram per square meter per centimeter (of depth)	kg m^{-2} cm^{-1}	pound per square foot per inch (of depth)	lb ft^{-2} in^{-1}	1 kg $m^{-2}cm^{-1}$ = 0.5202 lb $ft^{-2}in^{-1}$ 1 lb ft^{-2} in^{-1} = 1.922 kg m^{-2} cm^{-1}
Storm Total	kilogram per square meter	kg m^{-2}	pound per square foot	lb ft^{-2}	1 kg m^{-2} = 0.2048 lb ft^{-2} 1 lb ft^{-2} = 4.882 kg m^{-3}

TABLE 1.1 CONVERSION OF UNITS (CONTD)

TYPE OF DATA	METRIC		U.S. CUSTOMARY		CONVERSION
	UNIT	ABBREVIATION	UNIT	ABBREVIATION	
WIND Wind Speed	meter per second	$m\ sec^{-1}$	mile per hour knots feet per second	mph knots $ft\ sec^{-1}$	$1\ m\ sec^{-1} = 2.2369$ mph 1 mph $= 0.44704\ m\ sec^{-1}$ $1\ m\ sec^{-1} = 1.9438$ knots 1 knot $= 0.51444\ m\ sec^{-1}$ $1\ m\ sec^{-1} = 3.281\ ft\ sec^{-1}$ $1\ ft\ sec^{-1} = 0.30480\ m\ sec^{-1}$
DENSITY Air, Dust, and Hail	gram per cubic centimeter	$g\ cm^{-3}$	pound per cubic foot	$lb\ ft^{-3}$	$1\ g\ cm^{-3} = 62.43\ lb\ ft^{-3}$ $1\ lb\ ft^{-3} = 0.016018\ g\ cm^{-3}$
Vapor Concentration	gram per cubic meter	$g\ m^{-3}$	grain per cubic foot	$gr\ ft^{-3}$	$1\ g\ m^{-3} = 0.437\ gr\ ft^{-3}$ $1\ gr\ ft^{-3} = 2.288\ g\ m^{-3}$
PRESSURE Atmosphere	newton per square meter millibar	newton m^{-2} mb	millimeter of mercury inch of mercury pound per square inch	mm Hg in. Hg $lb\ in.^{-2}$	1 newton $m^{-2} = 10^{-2}$ mb 1 mb $= 0.7506$ mm Hg 1 mm Hg $= 1.333$ mb 1 mb $= 0.02953$ in. Hg 1 in. Hg $= 33.86$ mb 1 mb $= 1.4504 \times 10^{-2}\ lb\ in.^{-2}$ $1\ lb\ in.^{-2} = 68.95$ mb
	dyne per square centimeter	dyne cm^{-2}	pound per square inch	$lb\ in.^{-2}$	1.000×10^{-3} dyne cm^{-2} = $1.4504 \times 10^{-2}\ lb\ in.^{-2}$
	millibar to kilogram per square meter	mb to $kg\ m^{-2}$			1 mb $= 1.000 \times 10^{-3}$ dyne cm^{-2} 1 mb $= 10.1972\ kg\ m^{-2}$
OTHER Distance	meter micron	m μ	feet inch	ft in.	$1\ m = 3.2808$ ft $1\ ft = 0.3048$ m* $1\ \mu = 3.937 \times 10^{-3}\ in.^{-3}$
Mass	gram kilogram	g kg	grain pound	gr lb	$1\ g = 15.4324$ gr $1\ gr = 0.06480$ g $1\ kg = 2.20462$ lb $1\ lb \Rightarrow 0.45359237$ kg*

*Defined Exact Relations

FIGURE 1.1 GEOGRAPHICAL AREAS COVERED IN DOCUMENT

SECTION II. TEMPERATURE

2.1 Definitions.

Air temperature (surface) is the free or ambient air temperature measured under standard conditions of height, ventilation, and radiation shielding. The air temperature is normally measured with liquid-in-glass thermometers in a louvered wooden shelter, painted white inside and outside, with the base of the shelter normally 1.22 m (four feet) above a close-cropped grass surface (ref. 6, page 59). Unless an exception is stated, surface air temperatures given in this report are temperatures measured under these standard conditions.

Radiation temperature is the temperature of a radiating body (assumed as black) determined by Wien's displacement law, expressed as:

$$T_R = \frac{w}{\lambda_{max}} \qquad \text{Eq. (1)}$$

where:

T_R = Radiation temperature (°K)

w = Wien's displacement constant (0.2898 cm °K)

λ_{max} = The wave length corresponding to the maximum energy of radiation (cm)

Surface temperature is the temperature which a given surface will have when exposed to air temperature and radiation within the approximate wave-length interval of 0.15 to 20.0 microns. Extremes of surface temperatures will be dependent on the emittance of the surface, angle between the surface and the radiation source (such as the sun or sky), the radiation temperature of the source, and the subtended angle of the source.

Sky radiation temperature is the average radiation temperature of the sky assumed as a black body. Sky radiation is the radiation to and through the atmosphere to outer space. While this radiation is normally termed nocturnal radiation, it takes place under clear skies, even during daylight hours.

Solar radiation is the total electromagnetic energy emitted by the sun at wave lengths between 0.01 microns and 4.0 microns. About one-half of the total energy as measured at the surface of the earth is within the visible spectrum (0.4 to 0.7 microns), one-half in the infrared (0.7 to 4.0 microns) and a small portion in the ultraviolet (0.35 to 0.4 microns).

Emittance is the ratio of the energy emitted by a body to the energy which would be emitted by a black body at the same temperature. A black body has an emittance of 1.0.

2.2 Solar Radiation.

Maximum solar radiation intensity near the ground is presented in Table 2.1 for several geographical areas. The extreme values are given for a horizontal surface, a surface normal to the sun, and a surface inclined 45 degrees to the horizon with the normal at the surface facing south.

Generally, solar radiation data includes diffuse sky radiation (about 15 percent of the total radiation) measured on a horizontal surface. In this report, solar radiation values are given as intensities of direct solar and diffuse sky radiation, measured on a surface normal to the sun. Solar radiation intensity is presented in gram calories per square centimeter or langleys per square centimeter. When intensities of solar radiation are used, it is understood that the rate is per minute.

Normal incident solar radiation intensity was computed from the measured data using the following equation (refs. 11 and 13):

$$I_o = \frac{I}{\sin b} \qquad \text{Eq. (2)}$$

where:

I_o = Intensity of normal incident plus sky radiation*

* It is recognized that this method of computing I_o gives values of I_o with an error; however, during times of occurrence of maximum (extreme) values of solar radiation, the sky radiation is at a minimum and therefore the error is smaller than the error of measurement of such data. Research and development programs are being conducted to resolve this problem for other than maximum values.

I = Intensity of solar radiation incident on horizontal surface

b = Sun's altitude (ref. 12)

TABLE 2.1 SOLAR RADIATION MAXIMUM VALUES AT EARTH'S SURFACE

Area	Units	Normal Surface	Horizontal Surface		45° South-Facing Surface	
			Summer	Winter	Summer	Winter
Huntsville & River Transportation	$kJ\ m^{-2}\ sec^{-1}$	1.29	1.27	0.69	0.93	1.19
	$g\text{-}cal\ cm^{-2}\ min^{-1}$	1.85	1.82	0.99	1.33	1.70
	$BTU\ ft^{-2}\ hr^{-1}$	409	402	219	294	376
New Orleans, Gulf Transportation and Atlantic Missile Range	$kJ\ m^{-2}\ sec^{-1}$	1.12	1.11	0.66	0.87	1.12
	$g\text{-}cal\ cm^{-2}\ min^{-1}$	1.60	1.59	0.95	1.25	1.60
	$BTU\ ft^{-2}\ hr^{-1}$	354	352	221	277	354
Pacific Missile Range	$kJ\ m^{-2}\ sec^{-1}$	1.29	1.27	0.69	0.93	1.19
	$g\text{-}cal\ cm^{-2}\ min^{-1}$	1.85	1.82	0.99	1.33	1.70
	$BTU\ ft^{-2}\ hr^{-1}$	409	402	219	294	376
West Coast Transportation and Sacramento	$kJ\ m^{-2}\ sec^{-1}$	1.29	1.29	0.61	0.95	1.24
	$g\text{-}cal\ cm^{-2}\ min^{-1}$	1.85	1.85	0.88	1.36	1.77
	$BTU\ ft^{-2}\ hr^{-1}$	409	409	195	301	392
Wallops Test Range	$kJ\ m^{-2}\ sec^{-1}$	1.29	1.24	0.54	1.14	1.17
	$g\text{-}cal\ cm^{-2}\ min^{-1}$	1.85	1.77	0.78	1.63	1.68
	$BTU\ ft^{-2}\ hr^{-1}$	409	392	172	360	372
White Sands Missile Range	$kJ\ m^{-2}\ sec^{-1}$	1.29	1.28	0.71	1.05	1.25
	$g\text{-}cal\ cm^{-2}\ min^{-1}$	1.85	1.83	1.02	1.50	1.79
	$BTU\ ft^{-2}\ hr^{-1}$	409	405	225	332	396

When winds occur which exceed the 95, 99, or 99.9 percentile steady-state winds given in this document in paragraph 5.1, the associated weather normally is such that clouds, rain, or dust are generally present; therefore, the intensity of the incoming solar radiation would be less than the maximum values given in Table 2.1. Maximum values of solar radiation intensity to use with corresponding wind speeds are given in Table 2.2.

Solar radiation intensity on a south-facing surface, 45 degrees to the horizontal, were found as follows:

$$I_{45} = I\,(\sin 45° + \cot b \cos a \cos 45°) \qquad \text{Eq. (3)}$$

where

I_{45} = Intensity of solar radiation on a south-facing surface, 45 degrees to the horizontal, plus intensity of sky radiation

I = Intensity of solar radiation incident on a horizontal plane

a = Sun's azimuth measured from south direction

b = Sun's altitude.

Distributions of solar radiation intensity (extreme values) with time of day are given in Table 2.3.

Solar radiation intensity on a surface will vary with height above the earth's surface, with clear skies, in accordance with the following equation:

$$I_H = I_S + (1.40 - I_S)\left(1 - \frac{\rho_H}{\rho_S}\right) \qquad \text{Eq. (4)}$$

where

I_H = Intensity of solar radiation normal to surface at required height

I_S = Intensity of solar radiation normal to surface at the earth's surface, assuming clear skies

ρ_H = Atmospheric density at required height (from U. S. Standard Atmosphere Data or this document)

ρ_S = Atmospheric density at earth's surface

1.40 = Solar constant (kJ m^{-2} sec^{-1})

TABLE 2.2 SOLAR RADIATION MAXIMUM VALUES ASSOCIATED WITH EXTREME WIND VALUES

	Maximum Solar Radiation					
Steady-State Ground Wind Speed at 18 m Height	Huntsville, New Orleans River Transportation, Gulf Transportation, Atlantic Missile Range, Pacific Missile Range, Sacramento, West Coast Transportation and Wallops Test Range			White Sands Missile Range		
($m\ sec^{-1}$)	($kJ\ m^{-2}\ sec^{-1}$)	($g\text{-}cal\ cm^{-2}\ min^{-1}$)	($BTU\ ft^{-2}\ hr^{-1}$)	($kJ\ m^{-2}\ sec^{-1}$)	($g\text{-}cal\ cm^{-2}\ min^{-1}$)	($BTU\ ft^{-2}\ hr^{-1}$)
10	0.84	1.20	265	1.05	1.50	332
15	0.56	0.80	177	0.70	1.00	221
$\geq$20	0.35	0.50	111	0.56	0.80	177

TABLE 2.3 HOURLY DISTRIBUTION OF EXTREME VALUES OF SOLAR RADIATION

Time of Day (Local Standard Time)	Huntsville, River Transportation, West Coast Transportation, Sacramento, White Sands, and Pacific Missile Range			New Orleans, Gulf Transportation, and Atlantic Missile Range			Wallops Test Range		
	Normal Incident	Horizontal Surface		Normal Incident	Horizontal Surface		Normal Incident	Horizontal Surface	
		Summer	Winter		Summer	Winter		Summer	Winter
	$kJ\ m^{-2}\ sec^{-1}$			$kJ\ m^{-2}\ sec^{-1}$			$kJ\ m^{-2}\ sec^{-1}$		
0500	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0600	0.82	0.27	0.00	0.71	0.23	0.00	0.82	0.18	0.00
0700	1.02	0.53	0.11	0.88	0.47	0.11	1.02	0.44	0.00
0800	1.14	0.77	0.21	0.98	0.68	0.20	1.14	0.69	0.14
0900	1.20	0.98	0.40	1.04	0.85	0.39	1.20	0.91	0.33
1000	1.25	1.14	0.56	1.08	1.00	0.54	1.25	1.09	0.50
1100	1.28	1.23	0.66	1.10	1.07	0.63	1.28	1.21	0.59
1200	1.29	1.27	0.69	1.12	1.11	0.66	1.29	1.26	0.63
1300	1.28	1.23	0.66	1.10	1.07	0.63	1.28	1.21	0.59
1400	1.25	1.14	0.56	1.08	1.00	0.54	1.25	1.09	0.50
1500	1.20	0.98	0.40	1.04	0.85	0.39	1.20	0.91	0.33
1600	1.14	0.77	0.21	0.98	0.68	0.20	1.14	0.69	0.14
1700	1.02	0.53	0.11	0.88	0.47	0.11	1.02	0.44	0.00
1800	0.82	0.27	0.00	0.71	0.23	0.00	0.82	0.18	0.00
1900	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

The assumption in equation four is that the distance from the sun is one astronomical unit. When this distance differs from one astronomical unit, adjustment can be made using the following equation:

$$L_V = \frac{1.40}{D_V^2} \qquad \text{Eq. (5)}$$

where

L_V = Intensity of solar radiation normal to the surface at required distance (D_V) from the sun

D_V = Distance from the sun in astronomical units

Solar radiation may be reflected or re-radiated by the earth or other solar bodies. The nature of the reflected radiation or re-radiation is extremely complex because of the constant changing relative positions of the earth, sun, and other bodies. The reflected radiation and re-radiation could reach a maximum value of about 2.09 kJ m^{-2} sec^{-1} in addition to the direct solar radiation, but normally the earth contributed radiation is about 0.70 kJ m^{-2} sec^{-1} or less. Further information on computation of these values can be obtained from references 14, 15, 16, and 17.

2.3 Air Temperature Near the Surface.

Surface air temperatures are presented in Table 2.4 for various geographic areas. The maximum and minimum extremes and the 95 percentile values are given for the worst month based on 50 years of record. Values for extreme minimum sky radiation (equal to outgoing radiation) are also given in Table 2.4. The surface air temperature extreme values presented in Table 2.4 will be expected for only a few hours during a day. Generally, the extreme maximum temperature is reached after 12 noon and before 5 p.m., while the minimum temperature is reached just before sunrise. Table 2.5 shows the maximum and minimum air temperatures, with the associated hourly measurements, that have been recorded at the Atlantic Missile Range (Cape Kennedy).

TABLE 2.4 SURFACE AIR AND SKY RADIATION TEMPERATURE EXTREMES

Area		Surface Air Temperature Extremes**				Sky Radiation (Equivalent Temperature) Minimum Extreme
		Maximum		Minimum		
		Extreme	95%	Extreme	95%	
Huntsville	°C	43.9	*	-25.0	*	-30.0
	°F	111	*	-13	*	-22
River Transportation	°C	43.9	*	-25.0	*	-30.0
	°F	111	*	-13	*	-22
New Orleans	°C	37.8	31.7	-12.8	7.8	-17.8
	°F	100	89	9	46	0
Gulf Transportation	°C	40.6	*	-12.8	*	-17.8
	°F	105	*	9	*	0
Atlantic Missile Range	°C	37.2	30.0	- 2.2	12.2	-15.0
	°F	99	86	28	54	5
Panama Canal Transportation	°C	41.7	*	- 2.2	*	-15.0
	°F	107	*	28	*	5
Pacific Missile Range	°C	41.7	31.1	- 2.2	3.9	-15.0
	°F	107	88	28	39	5
West Coast Transportation	°C	46.1	*	- 6.1	*	-17.8
	°F	115	*	21	*	0
Sacramento	°C	46.1	*	- 6.1	*	-17.8
	°F	115	*	21	*	0
White Sands Missile Range	°C	42.8	*	-21.1	*	-30.0
	°F	109	*	- 6	*	-22
Wallops Test Range	°C	39.4	*	-11.7	*	-17.8
	°F	103	*	11	*	0

* To be determined

** The extreme maximum and minimum temperatures will be encountered during periods of wind speeds less than about one meter per second.

TABLE 2.5 MAXIMUM AND MINIMUM SURFACE AIR TEMPERATURES AT EACH HOUR FOR ATLANTIC MISSILE RANGE*

Time	Annual Maximum		Annual Minimum	
	°C	°F	°C	°F
1 a.m.	28.9	84	1.1	34
2	28.9	84	0.6	33
3	29.4	85	-1.1	30
4	28.3	83	-0.6	31
5	28.3	83	-1.1	30
6	29.4	85	-1.1	30
7	30.6	87	-1.7	29
8	30.6	87	-2.2	28
9	31.7	89	-0.6	31
10	33.9	93	1.1	34
11	35.0	95	2.2	36
12 noon	35.6	96	5.0	41
1 p.m.	37.2	99	5.6	42
2	35.6	97	5.0	41
3	35.6	97	5.6	42
4	35.6	97	5.6	42
5	35.6	97	5.6	42
6	35.0	95	3.9	39
7	33.3	92	2.2	36
8	31.7	89	2.2	36
9	30.0	86	1.7	35
10	30.0	86	1.7	35
11	30.0	86	1.1	34
12 mid	30.0	86	1.1	34

*Based on 10 years of record for Patrick AFB and Cape Kennedy.

2.4 Extreme Temperature Change

Suggested values of extreme temperature changes (thermal shock).

a. For all areas these values are:

(1) An increase of temperature of 10°C (18°F) with a simultaneous increase of solar radiation (measured on a normal surface) from 0.35 kJ m^{-2} sec^{-1} (0.50 g cal cm^{-2} min^{-1}) (110 BTU ft^{-2} hr^{-1}) to 1.29 kJ m^{-2} sec^{-1} (1.85 g cal cm^{-2} min^{-1}) (410 BTU ft^{-2} hr^{-1}) may occur in a one-hour period. Likewise, the reverse change of the same magnitude may occur for decreasing air temperature and solar radiation.

(2) A 24-hour change may occur with an increase of 27.7°C (50°F) in temperature in a 5-hour period, followed by 10 hours of constant temperature.

b. For Cape Kennedy, Florida, the 99.9 percentile temperature changes are as follows (ref. 22):

(1) An increase of temperature of 5.6°C (11°F) with a simultaneous increase of solar radiation (measured on a normal surface) from 0.50 g cal cm^{-2} min^{-1} (110 BTU ft^{-2} hr^{-1}) to 1.60 g cal cm^{-2} min^{-1} (354 BTU ft^{-2} hr^{-1}), or a decrease of temperature of 9.4°C (17°F) with a simultaneous decrease of solar radiation from 1.60 g cal cm^{-2} min^{-1} (354 BTU ft^{-2} hr^{-1}) to 0.50 g cal cm^{-2} min^{-1} (110 BTU ft^{-2} hr^{-1}) may occur in a one-hour period.

(2) A 24-hour temperature change may occur as follows. An increase of 16.1° C (29° F) in temperature (wind speed under 5 m/sec) in an eight-hour period, followed by two hours of constant temperature (wind speed under 5 m/sec), then a decrease of 21.7° C (39° F) in temperature (wind speed between 7 and 10 m/sec) in a 14-hour period.

2.5 Air Temperature at Altitude.

a. Atlantic Missile Range air temperatures at various altitudes are given in Table 2.6 (refs. 20 and 21).

b. Pacific Missile Range air temperature extreme values with altitude are to be determined.

c. Wallops Test Range air temperature extreme values with altitude are given in Table 2.7.

d. White Sands Missile Range air temperature extreme values with altitude are given in Table 2.8.

TABLE 2.6 AIR TEMPERATURES AT VARIOUS ALTITUDES FOR ATLANTIC MISSILE RANGE

Geometric Altitude (km)	Minimum (°C)	Minimum (°F)	Median (°C)	Median (°F)	Maximum (°C)	Maximum (°F)
SRF (0.005 MSL)	- 2.2	28	23.9	75	37.2	99
1	- 8.9	16	17.2	63	27.8	82
2	-10.0	14	12.2	54	21.1	70
3	-11.1	12	7.2	45	16.1	61
4	-13.9	7	2.2	36	11.1	52
5	-20.0	- 4	- 3.9	25	5.0	41
6	-26.1	- 15	-10.0	14	- 1.1	30
7	-33.9	- 29	-17.2	1	- 7.2	19
8	-41.1	- 42	-25.0	-13	-13.9	7
9	-50.0	- 58	-32.2	-26	-21.1	- 6
10	-56.1	- 69	-40.0	-40	-30.0	-22
16.2	-80.0	-112	-70.0	-94	-57.8	-72
20	-76.1	-105	-62.8	-81	-47.8	-54
30	-58.9	- 74	-42.2	-44	-30.0	-22
40	-30.0	- 22	-17.8	0	2.2	36
50	-15.0	5	- 2.2	28	26.1	79
59	-37.8	- 36	-20.0	- 4	27.8	82
*						

* For higher altitudes see reference 3.

TABLE 2.7 AIR TEMPERATURE AT VARIOUS ALTITUDES FOR WALLOPS TEST RANGE

Geometric Altitude (km)	Minimum (°C)	(°F)	Median (°C)	(°F)	Maximum (°C)	(°F)
SRF (0.002 MSL)	-11.7	11	12.8	55	39.4	103
1	-21.1	- 6	10.0	50	31.1	88
2	-26.1	- 15	5.0	41	22.8	73
3	-30.0	- 22	1.1	34	15.0	59
4	-33.9	- 29	- 3.9	25	7.8	46
5	-40.0	- 40	-10.0	14	2.8	37
6	-43.9	- 47	-17.2	1	- 1.1	30
7	-47.8	- 54	-23.9	-11	- 7.8	18
8	-50.6	- 59	-32.2	-26	-15.0	5
9	-56.1	- 69	-38.9	-38	-21.1	- 6
10	-61.1	- 78	-45.0	-49	-27.2	-17
16.5	-77.8	-108	-62.2	-80	-47.2	-53
20	-71.1	- 96	-57.2	-71	-46.1	-51
30	-65.0	- 85	-43.9	-47	-27.2	-17
40*	-36.1	- 33	-12.2	10	6.1	43
44*	-20.0	- 4	0.0	32	17.2	63
50*	-22.2	- 8	-10.0	14	5.0	41
56*	-22.2	- 8	-11.1	12	5.0	41
**						

* Values based on less than 10 observations.
** For higher altitudes see reference 3.

TABLE 2.8 AIR TEMPERATURE AT VARIOUS ALTITUDES FOR WHITE SANDS MISSILE RANGE

Geometric Altitude (km)	Minimum (°C)	Minimum (°F)	Median (°C)	Median (°F)	Maximum (°C)	Maximum (°F)
SRF (1.2 MSL)	-11.7	11	16.1	61	42.8	109
2	-11.7	11	12.8	55	31.1	88
3	-18.9	- 2	6.1	43	22.2	72
4	-23.9	- 11	0.0	32	12.8	55
5	-31.1	- 24	- 7.2	19	6.1	43
6	-36.1	- 33	-13.9	7	0.0	32
7	-42.2	- 44	-20.0	- 4	- 7.2	19
8	-48.9	- 56	-30.0	-22	-13.9	7
9	-55.0	- 67	-37.2	-35	-21.1	- 6
10	-60.0	- 76	-42.8	-45	-27.2	-17
16.5	-80.0	-112	-67.2	-89	-47.8	-54
20	-77.8	-108	-60.0	-76	-52.2	-62
30	-58.9	- 74	-42.8	-45	-26.1	-15
40	-40.0	- 40	-13.9	7	20.0	68
50	-22.8	- 9	6.1	43	17.8	64
60	- 5.0	23	7.2	45	25.0	77
65	- 5.0	23	8.9	48	17.8	64
*						

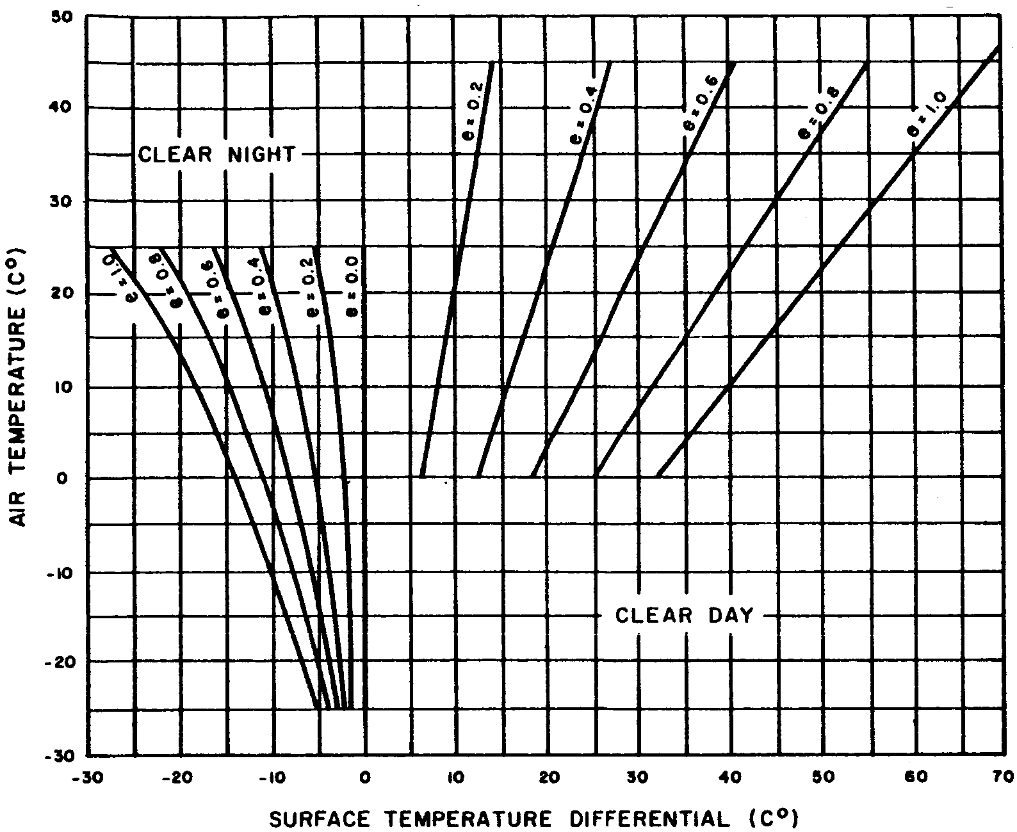
* For higher altitudes see reference 3.

2.6 Surface (Skin) Temperatures.

The surface temperature of an object exposed to radiation usually is different from the air temperature. Temperature differences between an object and the surrounding air when the object is exposed to the sun or clear night sky are given in Table 2.9 and in Figure 2.1, Part a. Wind has a considerable effect on the temperature difference by increasing the heat transfer at the surface. The graphical data given in Figure 2.1, Part b are to be used for making wind speed corrections.

2.7 Compartment Temperature.

A thin metal cover enclosing an air space will conduct the heat to the air next to the metal when heated by solar radiation (or cooled by the night sky). This results in a heating (or cooling) of the compartment air space. The temperature reached in a compartment is dependent on the location of the compartment with respect to the heated surface, the type of construction, the methods employed to dissipate the heat, and the insulation. Frequently this temperature is considerably different from the outside air temperature. The addition of a layer of insulation on the inside of the metal will greatly reduce the heating (or cooling) of the air space (refs. 18 and 19). A compartment probable extreme high temperature of 87.8°C (190°F) for a period of one hour and 65.6°C (150°F) for a period of six hours must be considered at all geographic locations while aircraft or other transportation equipment are stationary on the ground without having air conditioning in the compartment. These extreme temperatures will be found at the top and center of the compartment. Extreme cold temperatures during flight, when heat is not provided in the compartment, are given in Table 2.10.



A. SURFACE TEMPERATURE DIFFERENTIALS WITH RESPECT TO AIR TEMPERATURE FOR SURFACE OF EMITTANCE FROM 0.0 TO 1.0 FOR CALM WIND CONDITIONS. TEMPERATURE DIFFERENCE AFTER CORRECTION FOR WIND IS TO BE ADDED OR SUBTRACTED TO THE AIR TEMPERATURE TO GIVE SURFACE (SKIN) TEMPERATURE

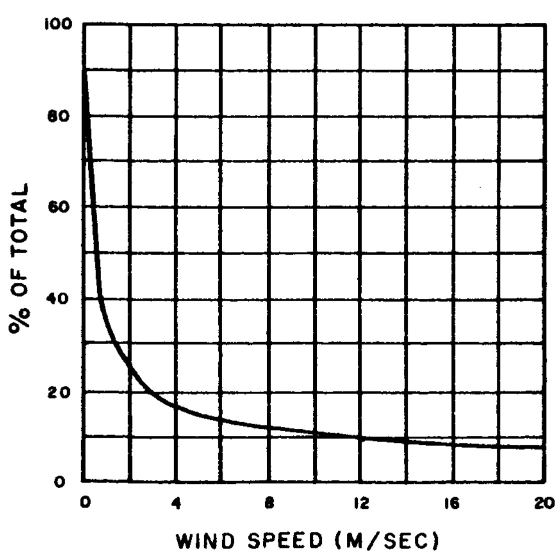


FIGURE 2.1 EXTREME SURFACE (SKIN) TEMPERATURE OF AN OBJECT NEAR THE EARTH'S SURFACE (0 TO 300 m) FOR CLEAR SKY

B. CORRECTION FOR WIND SPEED OBTAINED FROM GRAPH A. VALID ONLY FOR A PRESSURE OF ONE ATMOSPHERE.

TABLE 2.9 EXTREME SURFACE (SKIN) TEMPERATURE ABOVE OR BELOW AIR TEMPERATURE OF AN OBJECT NEAR THE EARTH'S SURFACE

Air Temperature	Clear Night					Clear Day				
	Wind Speed (m sec^{-1})					Wind Speed (m sec^{-1})				
	0	2	4	10	20	0	2	4	10	20
(°C)	Surface Temperatures (°C)					Surface Temperatures (°C)				
-25	- 5.0	-1.1	-0.8	-0.2	-0.15					
-20	- 6.5	-1.5	-1.0	-0.3	-0.2					
-15	- 8.0	-1.8	-1.3	-0.4	-0.2					
-10	-10.0	-2.3	-1.6	-0.4	-0.3					
- 5	-12.0	-2.7	-1.9	-0.5	-0.4					
0	-14.2	-3.2	-2.3	-0.6	-0.4	32.0	7.3	5.1	1.4	1.0
5	-16.6	-3.8	-2.7	-0.7	-0.5	36.0	8.2	5.8	1.6	1.1
10	-19.2	-4.4	-3.1	-0.9	-0.6	40.0	9.1	6.4	1.8	1.2
15	-22.0	-5.0	-3.5	-1.0	-0.7	44.0	10.0	7.0	2.0	1.3
20	-25.0	-5.7	-4.0	-1.1	-0.8	48.0	10.9	7.7	2.2	1.4
25	-28.0	-6.4	-4.5	-1.3	-0.8	52.0	11.8	8.3	2.3	1.6
30						56.0	12.7	9.0	2.5	1.7
35						60.0	13.6	9.6	2.7	1.8
40						64.0	14.5	10.2	2.9	1.9
45						68.0	15.4	10.9	3.1	2.0

Note: Values are given for an emittance value of 1.0. Temperature differences for other emittance can be determined by multiplying tabular value by the appropriate emittance.

TABLE 2.10 COMPARTMENT DESIGN COLD TEMPERATURE EXTREMES FOR ALL LOCATIONS

Maximum Flight Altitude (Geometric) Of Aircraft Used For Transport		Compartment Cold Temperature Extreme	
(m)	(ft)	(°C)	(°F)
4,550	15,000	-35.0	- 31
6,100	20,000	-45.0	- 49
7,600	25,000	-53.3	- 64
9,150	30,000	-65.0	- 85
15,200	50,000	-86.1	-123

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SECTION III. HUMIDITY

3.1 Definitions. (Ref. 4)

Dew point is the temperature to which a given parcel of air must be cooled at constant pressure and constant water vapor content in order for saturation to occur. Further cooling below the dew point normally produces condensation either in liquid or solid form.

Relative humidity is the ratio of the actual amount of water vapor in a given volume of air to the amount of water vapor that the same volume of air at the same temperature would hold if saturated. Values given are in percent.

Vapor concentration (previously called absolute humidity, ref. 7) is the ratio of the mass of water vapor present to the volume occupied by the mixture, i.e., the density of the water vapor content. This is expressed in grams of water vapor per cubic meter of air.

Water vapor is water in gaseous state.

3.2 Vapor Concentration.

Water in vapor form in the atmosphere is invisible; however, the amount of liquid water available from a volume of warm air near saturation is considerable and must be considered in design of space vehicles because:

a. Small solid particles (dust) which settle on surfaces cause condensation (frequently when the atmosphere is not at the saturation level) and will dissolve. The resultant solution may be corrosive. Galvanic corrosion resulting from contact of dissimilar metals also takes place at a rapid rate in the presence of moisture. The rate of corrosion of the surface increases with higher humidity (ref. 23).

b. Humidity conditions can impair the performance of electrical equipment. This may be by an alteration of the electrical constants of tuned circuits, deterioration of parts (resistors, capacitors, etc.), electrical breakdown of air gaps in high-voltage areas, or shorting of sections by conductive solutions formed from solid particles dissolving in the liquid formed.

c. Bacteria and fungi usually require high humidities associated with high temperatures to grow well.

d. A decrease in the temperature of the air to the dew point will result in condensation of water from the atmosphere in liquid or frozen form. Considerable difficulty may result from ice forming on space vehicles when moist air is cooled by the low temperature of the fuel used, especially if pieces of this ice should drop into equipment areas of the vehicle or supporting ground equipment before or during takeoff. Optical surfaces (such as lenses of television cameras) may become coated with water droplets or ice crystals which prevent their use.

Tests are specified for environmental testing (humidity) for aeronautical equipment in MIL-E-5272C (ASG) 13 April 1959 (ref. 24), and are included in Proposed MIL-STD-810 (USAF) (ref. 25). These tests specify temperatures of 71.1°C (160°F) at a relative humidity of 95 percent ± 5 percent for 10 cycles of 6 hours each over a total period of 240 hours. This represents dew points of 68.9°C (156°F), values far higher than any natural extreme. Dew points much above 32.2°C (90°F) are extremely unlikely in nature (ref. 26), since the dew point is limited by the source of the moisture, that is the surface temperature of the water body from which the water evaporates (see ref. 27, maps following page 235 for average ocean temperatures). The tests proposed can be used advantageously only as aggravated tests after correlation of deterioration with that encountered in natural extremes. Therefore, the referenced Military Specifications should be used as guidelines in conjunction with this document.

3.2.1 High Vapor Concentration at Surface.

a. Huntsville, River Transportation, New Orleans, Gulf Transportation, Atlantic Missile Range and Wallops Test Range:

(1) An extreme humidity cycle of 24 hours with a steady-state wind of less than 5 m sec^{-1} (9.7 knots) as follows should be considered in design: six hours of 37.2°C (99°F) air temperature at 50 percent relative humidity and a vapor concentration of 26.9 g m^{-3} (11.7 gr ft^{-3}); six hours of decreasing air temperature to 24.4°C (76°F) with relative humidity increasing to 100 percent (saturation); eight hours of decreasing air temperature to 21.1°C (70°F), with a release of 3.9 grams of water as fluid per cubic meter of air

(1.7 gr ft^{-3}), humidity remaining at 100 percent; and four hours of increasing air temperature to 37.2°C (99°F) and a decrease to 41 percent relative humidity.

(2) An extreme relative humidity between 75 and 100 percent and air temperature between 22.8°C (73°F) and 27.8°C (82°F), which would result in corrosion and bacterial and fungal growths, can be expected for a period of 15 days. A humidity of 100 percent occurs one-fourth of the time at the lower temperature in cycles not exceeding 24 hours. Any loss of water vapor from the air by condensation is replaced from outside sources so that 75 percent relative humidity is maintained at the higher temperature.

b. Panama Canal Transportation:

(1) An extreme humidity cycle of 24 hours with a steady-state wind of less than 5 m sec^{-1} (9.7 knots) as follows should be considered in design: six hours of 32.2°C (90°F) air temperature at 75 percent relative humidity, and a vapor concentration of 25.4 g m^{-3} (11.1 gr ft^{-3}); six hours of decreasing air temperature to 26.7°C (80°F) with relative humidity increasing to 100 percent; eight hours of decreasing air temperature to 21.7°C (71°F) with a release of 6.3 grams of water as liquid per cubic meter of air (2.8 gr of water per cubic foot of air), humidity remaining at 100 percent; two hours of increasing air temperature to 26.7°C (80°F) and a decrease to 75 percent relative humidity; and two hours of increasing air temperature to 32.2°C (90°F) with the relative humidity remaining at 75 percent (moisture added to air by evaporation, mixing, or replacement with air of higher vapor concentration).

(2) An extreme relative humidity between 85 and 100 percent and air temperature between 23.9°C (75°F) and 26.1°C (79°F), which would result in corrosion and bacterial and fungal growth, can be expected for a period of 30 days. The humidity should be 100 percent during one-fourth of the time at the lower temperature in cycles not exceeding 24 hours. Any loss of water vapor from the air by condensation is replaced from outside sources so that at least 85 percent relative humidity is maintained at the higher temperature.

(3) Equipment shipped from the west coast, through the Panama Canal transported by ship may accumulate moisture (condensation) while in the ship's hold because of the increasing moisture content of the air while

traveling south to the Panama Canal, and the slower increase of temperature of the equipment being transported. This condensation may result in corrosion, rusting or other deterioration of the equipment (ref. 58). Extreme values of condensation conditions are

(a) Maximum condensation conditions occur during the period between December and March, but condensation conditions may occur during all months.

(b) The maximum dew point expected is 30.0°C (86°F), with dew points over 21.1°C (70°F) for ship travel of 6 days prior to arrival at the Panama Canal from the west coast; and for the remainder of the trip to Cape Canaveral.

c. Pacific Missile Range, West Coast Transportation, and Sacramento:

(1) An extreme humidity cycle of 24 hours with a steady-state wind of less than 5 m sec^{-1} (9.7 knots) as follows should be considered in design: six hours of 23.9°C (75°F) air temperature at 75 percent relative humidity and a vapor concentration of 16.2 g m^{-3} (7.9 gr ft^{-3}); six hours of decreasing air temperature to 18.9°C (66°F) with relative humidity increasing to 100 percent; eight hours of decreasing air temperature to 12.8°C (55°F) with a release of 5.0 grams of water as liquid per cubic meter of air (2.2 gr of water per ft^3 of air), humidity at 100 percent; and four hours of increasing air temperature to 23.9°C (75°F) and the relative humidity decreasing to 52 percent.

(2) Bacterial and fungal growth should present no problem because of the lower temperatures in this area. For corrosion, an extreme humidity of between 75 and 100 percent relative humidity and air temperature between 18.3°C (65°F) and 23.3°C (74°F) can be expected for a period of 15 days. The humidity should be 100 percent during one-fourth of the time at the lower temperature in cycles not exceeding 24 hours. Any loss of water vapor from the air by condensation should be replaced from outside sources to maintain at least 75 percent relative humidity at the higher temperature.

d. White Sands Missile Range: At this location, a high-vapor concentration need not be considered.

3.2.2 High Vapor Concentration at Altitude.

The following tables present the relationship between maximum vapor concentration and the associated temperature normally expected as a function of altitude.

a. Maximum Vapor Concentrations for Atlantic Missile Range, Table 3.1.

b. Maximum Vapor Concentrations for Pacific Missile Range are to be determined.

c. Maximum Vapor Concentrations for Wallops Test Range, Table 3.2.

d. Maximum Vapor Concentrations for White Sands Missile Range, Table 3.3.

3.2.3 Low Vapor Concentration at Surface.

Low water-vapor concentration can occur when the air temperatures are very low or at high temperature when the air is very dry. In both cases, the dew points are very low. However, in the case of low dew points and high temperatures, the relative humidity is low. When any storage area or compartment of a vehicle is heated to temperatures well above the ambient air temperature (such as the high temperatures of the storage area in an aircraft standing on the ground in the sun), the relative humidity will be even lower than the relative humidity of the ambient air. These two types of low water-vapor concentrations have entirely different environment effects. In the case of low air temperatures, ice or condensation may form on equipment while in the high temperature—low humidity condition; organic materials may dry and split or otherwise deteriorate. When a storage area (or aircraft) is considerably warmer than the ambient air (even when the air is cold), the drying increases even more. Low relative humidities may also result in another problem – that of static electricity. Charges on equipment could ignite fuel or result in shocks to personnel when discharged. Because of this, two types of low water-vapor concentrations (dry extremes) are given for the surface.

TABLE 3.1 MAXIMUM VAPOR CONCENTRATION FOR ATLANTIC MISSILE RANGE

Geometric Altitude		Vapor Concentration		Temperature Associated with Maximum Vapor Concentration	
(km)	(ft)	(g m^{-3})	(gr ft^{-3})	(°C)	(°F)
SRF (0.005 MSL)	(16)	27.0	11.8	30.5	87
1	3,300	19.0	8.3	24.5	76
2	6,600	13.3	5.8	18.0	64
3	9,800	9.3	4.1	12.0	54
4	13,100	6.3	2.8	5.5	42
5	16,400	4.5	2.0	- 0.5	31
6	19,700	2.9	1.3	- 6.8	20
7	23,000	2.0	0.9	-13.0	9
8	26,200	1.2	0.5	-20.0	- 4
9	29,500	0.6	0.3	-27.0	-17
10	32,800	0.3	0.1	-34.5	-30
10 to 20	32,800 to 65,600	0.3	0.1	-34.5	-30

TABLE 3.2 MAXIMUM VAPOR CONCENTRATION FOR WALLOPS TEST RANGE

Geometric Altitude		Vapor Concentration		Temperature Associated with Maximum Vapor Concentration	
(km)	(ft)	(g m^{-3})	(gr ft^{-3})	(°C)	(°F)
SRF (0.002 MSL)	(8)	22.5	9.8	27.5	81
1	3,300	20.0	8.7	26.1	79
2	6,600	13.9	6.1	17.2	63
3	9,800	10.3	4.5	12.8	55
4	13,100	7.4	3.2	7.8	46
5	16,400	6.0	2.6	2.8	37
6	19,700	3.9	1.7	- 1.1	30
7	23,000	2.6	1.1	- 5.0	23
8	26,200	1.7	0.7	-11.1	12
9	29,500	0.9	0.4	-17.8	0
10	32,800	0.4	0.2	-27.8	-18
10 to 20	32,800 to 65,600	0.4	0.2	-27.8	-18

TABLE 3.3 MAXIMUM VAPOR CONCENTRATION FOR WHITE SANDS MISSILE RANGE

Geometric Altitude		Vapor Concentration		Temperature Associated with Maximum Vapor Concentration	
(km)	(ft)	(g m^{-3})	(gr ft^{-3})	(°C)	(°F)
SRF (1.2 MSL)	(3,989)	16.0	7.0	21.5	70
2	6,600	13.2	5.8	18.9	66
3	9,800	9.0	3.9	12.8	55
4	13,100	6.8	3.0	7.8	46
5	16,400	4.9	2.1	2.2	36
6	19,700	3.4	1.5	- 2.2	28
7	23,000	2.2	1.0	-10.0	14
8	26,200	1.3	0.6	-16.1	3
9	29,500	0.6	0.3	-22.8	- 9
10	32,800	0.2	0.1	-30.0	-22
10 to 20	32,800 to 65,600	0.2	0.1	-30.0	-22

3.2.3.1 Surface Extremes of Low Vapor Concentration.

a. Huntsville, River Transportation, Wallops Test Range, and White Sands Missile Range:

(1) A vapor concentration of 2.1 g m^{-3} (0.9 gr ft^{-3}), with an air temperature of -11.7°C (+11°F) and a relative humidity between 98 and 100 percent for a duration of 24 hours, must be considered.

(2) A vapor concentration of 4.5 g m^{-3} (2.0 gr ft^{-3}), corresponding to a dew point of -1.1°C (30°F) at an air temperature of 28.9°C (84°F) and a relative humidity of 15 percent occurring for 6 hours each 24 hours, and a maximum relative humidity of 34 percent at an air temperature of 15.6°C (60°F) for the remaining 18 hours of each 24 hours for a 10-day period, must be considered.

b. New Orleans, Gulf Transportation, Panama Canal Transportation, and Atlantic Missile Range:

(1) A vapor concentration of 4.2 g m^{-3} (1.8 gr ft^{-3}), with an air temperature of -2.2°C (28°F) and a relative humidity of 98 to 100 percent for a duration of 24 hours, must be considered.

(2) A vapor concentration of 5.6 g m^{-3} (2.4 gr ft^{-3}), corresponding to a dew point of 2.2°C (36°F) at an air temperature of 22.2°C (72°F) and a relative humidity of 29 percent occurring for 8 hours, and a maximum relative humidity of 42 percent at an air temperature of 15.6°C (60°F) for the remaining 16 hours of each 24 hours for 10 days, must be considered.

c. Pacific Missile Range:

(1) A vapor concentration of 4.2 g m^{-3} (1.8 gr ft^{-3}), with an air temperature of -2.2°C (28°F) and a relative humidity of 98 to 100 percent for a duration of 24 hours, must be considered.

(2) A vapor concentration of 4.8 g m^{-3} (2.1 gr ft^{-3}), corresponding to a dew point of 0.0°C (32°F) at an air temperature of 37.8°C (100°F) and a relative humidity of 11 percent occurring for 4 hours each 24 hours, and a maximum relative humidity of 26 percent at an air temperature of 21.1°C (70°F) for the remaining 20 hours of each 24 hours for 10 days, must be considered.

d. West Coast Transportation and Sacramento:

(1) A vapor concentration of 3.1 g m^{-3} (1.4 gr ft^{-3}), with an air temperature of -6.1°C (21°F) and a relative humidity of 98 to 100 percent for a duration of 24 hours, must be considered.

(2) A vapor concentration of 10.1 g m^{-3} (4.4 gr ft^{-3}), corresponding to a dew point of 11.1°C (52°F) at an air temperature of 37.8°C (100°F) and a relative humidity of 22 percent occurring for 4 hours each 24 hours, and a maximum relative humidity of 55 percent at an air temperature of 21.1°C (70°F) for the remaining 20 hours of each 24 hours for 10 days, must be considered.

3.2.3.2 Compartment Vapor Concentration. A low water-vapor concentration extreme of 10.1 g m^{-3} (4.4 gr ft^{-3}), corresponding to a dew point of 11.1°C (52°F) at an air temperature of 87.8°C (190°F) and a relative humidity of two percent occurring for one hour, a linear change over a four-hour period to an air temperature of 37.8°C (190°F) and a relative humidity of 21 percent occurring for 15 hours, then a linear change over a four-hour period to the initial conditions, must be considered at all locations.

3.2.3.3 Extremes for Altitude of Low Vapor Concentration. The values presented as low extreme vapor concentrations in the following tables are based on data measured by radiosondes.

a. Minimum Vapor Concentrations for Atlantic Missile Range, Table 3.4.

b. Minimum Vapor Concentrations for Pacific Missile Range is to be determined.

c. Minimum Vapor Concentrations for Wallops Test Range, Table 3.5.

d. Minimum Vapor Concentrations for White Sands Missile Range, Table 3.6.

TABLE 3.4 MINIMUM VAPOR CONCENTRATIONS FOR ATLANTIC MISSILE RANGE

Geometric Altitude		Vapor Concentration		Temperature Associated with Minimum Vapor Concentration	
(km)	(ft)	($g\ m^{-3}$)	($gr\ ft^{-3}$)	(°C)	(°F)
SRF (0.005 MSL)	(16)	4.0	1.7	29	84.2
1	3,300	0.5	0.2	6	42.8
2	6,600	0.2	0.1	0	32.0
3	9,800	0.1	0.04	- 6	21.2
4	13,100	<0.1	<0.04	-11	12.2

TABLE 3.5 MINIMUM VAPOR CONCENTRATION FOR WALLOPS TEST RANGE

Geometric Altitude		Vapor Concentration		Temperature Associated with Minimum Vapor Concentration	
(km)	(ft)	($g\ m^{-3}$)	($gr\ ft^{-3}$)	(°C)	(°F)
SRF (0.002 MSL)	(8)	0.5	0.2	- 4	24.8
1	3,300	0.3	0.1	-11	12.2
2	6,600	0.2	0.1	-17	1.4
3	9,800	0.2	0.1	-23	- 9.4
4	13,100	0.2	0.1	-31	-23.8
5	16,400	0.1	0.04	-39	-38.2
to	to				
10	32,800	0.1	0.04	-39	-38.2

TABLE 3.6 MINIMUM VAPOR CONCENTRATION FOR WHITE SANDS MISSILE RANGE

Geometric Altitude		Vapor Concentration		Temperature Associated with Minimum Vapor Concentration	
(km)	(ft)	(g m^{-3})	(gr ft^{-3})	(°C)	(°F)
SRF (1.2 MSL)	(3,989)	1.2	0.5	- 1	30.2
2	6,600	0.9	0.4	- 5	23.0
3	9,800	0.6	0.3	-12	10.4
4	13,100	0.4	0.2	-20	- 4.0
5	16,400	0.2	0.1	-26	- 4.8
6	19,700	0.1	0.04	-32	-25.6
7	23,000	0.1	0.04	-34	-29.2
8	26,200	0.1	0.04	-38	-36.4
9	29,500	0.1	0.04	-39	-38.2
10	32,800	0.1	0.04	-39	-38.2

SECTION IV. PRECIPITATION

4.1 Definitions. (Ref. 4)

Precipitation is defined as all forms of hydrometeors, whether liquid or solid, which are free in the atmosphere and which may or may not reach the ground. Accumulation is reported in inches of depth for liquid and ice, or in inches of depth of water, equivalent to frozen water particles.

Snow is defined as all forms of frozen precipitation except large hail; it includes snow pellets, snow grains, ice crystals, ice pellets, and small hail.

Hail is precipitation in the form of balls or irregular lumps of ice, and always is produced by convective clouds. Through established convention, the diameter of hail must be 5 mm or more, and the specific gravity between 0.60 and 0.92.

Ice pellets are precipitation in the form of transparent, more or less globular, hard grains of ice under 5 mm in diameter, that rebound when striking hard surfaces.

Small hail is precipitation in the form of semitransparent, round or conical grains of frozen water under 5 mm in diameter. Each grain consists of a nucleus of soft hail (ball of snow) surrounded by a very thin ice layer. They are not crisp and do not usually rebound when striking a hard surface.

Precipitable water is the total atmospheric water vapor contained in a vertical column of unit cross-sectional area extending between any two specified levels. It is usually given as inches of water (if vapor were completely condensed).

4.2 Rain.

Although most long-duration rainfall world records (monthly or yearly) have been for regions far removed from the areas of interest for large space vehicle launch and test operations, the world maximum amount of short-duration of rainfall has occurred or can occur in the thunderstorms or tropical storms within the United States, in the Gulf of Mexico, or in Canal Zone areas. A study of the rate of rainfall, compared with duration, shows that the average rate (per hour) decreases as the duration increases. Equipment must withstand both prolonged soaking rain and brief downpours. The following precipitation values at an air temperature between 21.1°C (70°F) (night) and 32.2°C (90°F) (day) are adequate for most design problems.

4.2.1 Rainfall at Surface.

a. Huntsville, Atlantic Missile Range, Pacific Missile Range, Sacramento, West Coast Transportation, River Transportation, White Sands Missile Range, Wallops Test Range, and New Orleans rainfall rates are given in Table 4.1.

b. Gulf Transportation and Panama Canal Transportation rainfall rates are given in Table 4.2.

TABLE 4.1 RAINFALL RATES BASED ON A RETURN PERIOD OF 10 YEARS FOR HUNTSVILLE, ATLANTIC MISSILE RANGE, PACIFIC MISSILE RANGE, SACRAMENTO, WEST COAST TRANSPORTATION, RIVER TRANSPORTATION, WALLOPS TEST RANGE, WHITE SANDS MISSILE RANGE AND NEW ORLEANS

Time Period	1 min	1 hour	24 hours
Total Amount (mm)	7.6	63	305
(in.)	0.3	2.5	12
Rate (mm/hr)	460	64	13
(in./hr)	18.0	2.5	0.5
Average Drop Diameter (mm)	3.8	2.6	2.0
Average Rate of Fall (m/sec)	8.5	7.3	6.4
Peak Wind Speed (m/sec)	20	20	20

TABLE 4.2 RAINFALL RATES BASED ON A RETURN PERIOD OF 10 YEARS FOR GULF TRANSPORTATION AND PANAMA CANAL

Time Period	1 min	1 hour	24 hours
Total Amount (mm)	12.7	102	508
(in.)	0.5	4	20
Rate (mm/hr)	762	102	20
(in./hr)	30.0	4.0	0.8
Average Drop Diameter (mm)	4.1	2.9	1.8
Average Rate of Fall (m/sec)	8.8	7.6	6.1
Peak Wind Speed (m/sec)	20	20	20

4.2.2 Rainfall at Altitude

Rainfall rates normally decrease with altitude when rain is striking the ground. The rainfall rates at various altitudes in percent of the surface rates are given in Table 4.3 for all areas (ref. 28).

TABLE 4.3 DISTRIBUTION OF RAINFALL RATES WITH HEIGHT FOR ALL LOCATIONS

Height (Geometric) Above Surface (km)	Percent of Surface Rate
SRF	100
1	90
2	75
3	57
4	34
5	15
6	7
7	2
8	1
9	0.1
10 and over	<0.1

The precipitation above the ground is generally colder than at the ground and frequently occurs as supercooled drops which can cause icing on any object moving through the drops. Such icing can be expected to occur when the air temperature is less than 2.2°C (36°F). For the geographic areas considered in this report, these conditions usually occur between 3 and 10 km altitude.

4.3 Snow.

The accumulation of snow on a surface produces stress. For a flat horizontal surface, the stress is proportional to the weight of the snow directly above the surface. For long narrow objects, such as pipes or wires lying horizontally above a flat surface (which can accumulate the snow), the stress can be figured as approximately equal to the weight of the wedge of snow with the sharp edge along the object and extending above the object in both directions at about 45 degrees to the vertical. (In such cases, the snow load would be computed for the depth of snow above the edge of the object and not the total snow depth on the ground.) The weight of new fallen snow varies between 0.5 kg m^{-2} per cm of depth (0.26 lb ft^{-2} $in.^{-1}$) and 2.0 kg m^{-2} per cm of depth (1.04 lb ft^{-2} $in.^{-1}$), depending on the weather situation at the time of snowfall. When the amount is sufficient to be important in load design, the weight is near 1.0 kg m^{-2} cm^{-1} (0.52 lb ft^{-2} $in.^{-1}$). Snow on the ground becomes more dense and the depth decreases with time.

4.3.1 Snow Loads at Surface.

Maximum snow loads for the following areas are:

a. Huntsville, Wallops Test Range, and River Transportation areas. For horizontal surfaces a snow load of 25 kg m^{-2} (5.1 lb ft^{-2}) per 24-hour period (equivalent to a 10-inch snowfall) to a maximum of 50 kg m^{-2} (10.2 lb ft^{-2}) in a 72-hour period, provided none of the snow is removed from the surface during the period, should be considered for design purposes.

b. New Orleans, West Coast Transportation, White Sands Missile Range, and Sacramento areas. For horizontal surfaces, a maximum snow load of 10 kg m^{-2} (2.0 lb ft^{-2}) per one 24-hour period, should be considered for design purposes.

4.3.2 Snow Particle Size.

Snow particles may penetrate openings (often openings of minute size) in equipment and cause malfunction of mechanical or electrical components, either before or after melting. Particle size, associated wind speed, and air temperature to be considered are as follows:

a. Huntsville, Wallops Test Range, and River Transportation areas. Snow particles 0.1 mm (0.0039 in.) to 5 mm (0.20 in.) diameter; wind speed 10 m sec^{-1} (19 knots); air temperature -17.8°C (0°F).

b. New Orleans, West Coast Transportation, White Sands Missile Range, and Sacramento areas. Snow particles 0.5 mm (0.020 in.) to 5 mm (0.20 in.) diameter; wind speed 10 m sec^{-1} (19 knots); air temperature -5.0°C (23°F).

4.4 Hail.

Hail is one of the most destructive weather forces in nature, being equalled only by hurricanes and tornadoes. Hail normally forms in extremely well-developed thunderstorms during warm weather and rarely occurs in winter months or when the air temperature is below 0°C (32°F). Although the average diameter of hailstones is 8 mm (0.31 in.) (ref. 29), hailstones larger than 12.7 mm (0.5 in.) in diameter frequently fall, while stones 50 mm (2.0 in.) in diameter can be expected annually somewhere in the United States. The largest measured hailstone in the United States was 137 mm (5.4 in.) in diameter and had a weight of 0.68 kg (1.5 lb) (refs. 30, 31, and 32). Three environmental effects on equipment must be considered; they are as follows:

The accumulation of hail, as with snow, stresses the object by its weight. Although hail has a higher density than snow, 2.4 kg m^{-2} cm^{-1} (1.25 lb ft^{-2} $in.^{-1}$), the extreme load from hail will not exceed the extreme snow load at any area of interest; therefore, the snow load design will adequately cover any hail loads expected.

Large hailstones, because of weight and velocity of fall, are responsible for structural damage to property (ref. 33). The actual designation of areas where hailstones, with specific sizes of hail, will fall is not possible. However, the following information can be used as a guide for design and scheduling (these values are most applicable to the design of ground support equipment and protective covering for the space vehicles during the transporting of vehicles between Huntsville and New Orleans).

4.4.1 Hail at Surface.

a. Huntsville, River Transportation, Gulf Transportation, New Orleans, Wallops Test Range, and White Sands Missile Range.

(1) A maximum hailstone size of 50 mm (2 in.) in diameter with a probability of one time in 15 years.

(2) Damaging hailstorms occur most frequently between 3 p.m. and 9 p.m. during May through September. April is the month of highest frequency-of-occurrence of hailstorms for Huntsville, River Transportation, and Gulf Transportation. March is the month of highest frequency-of-occurrence of hailstorms for White Sands Missile Range, and May is the month of highest frequency-of-occurrence of hailstorms for Wallops Test Range.

(3) The period of large hail (over 50 mm in diameter) will not be expected to last more than 15 minutes and should have a maximum total accumulation of 50 mm (2 in.) for depth of hailstones on horizontal surfaces.

(4) Velocity of fall equals 30.5 m sec^{-1} (100 ft sec^{-1}) for each stone.

(5) Wind speed equals 10 m sec^{-1} (33 ft sec^{-1}).

(6) Density of hailstones equals 0.80 g cm^{-3} (50 lb ft^{-3}).

b. Atlantic Missile Range.

(1) A maximum hailstone size of 25.4 mm (1 in.) in diameter with a probability of one time in 30 years.

(2) Damaging hailstones occur most frequently between 3 p.m. and 9 p.m. during April through June. May is the month of highest frequency-of-occurrence for hailstorms.

(3) The period of large hail will not be expected to last more than 15 minutes and should have a maximum total accumulation of 12.5 mm (0.5 in.) for depth of hailstones on horizontal surfaces.

(4) Velocity of fall equals 20 m sec^{-1} (66 ft sec^{-1}) for each stone.

(5) Wind speed equals 10 m sec^{-1} (33 ft sec^{-1}).

(6) Density of hailstones equals 0.80 g cm^{-3} (50 lb ft^{-3}).

4.4.2 Distribution of Hail with Altitude.

Although it is not the current practice to design space vehicles for flight in thunderstorms, data on distribution with altitude is presented as an item of importance. The probability of hail increases with altitude from the surface to 5 km and then decreases rapidly with increasing height. Data on Florida thunderstorms, giving the number of times hail was encountered at various altitudes during aircraft flights (ref. 34), are given in Table 4.4 for areas specified in paragraph 4.4.1.

TABLE 4.4 DISTRIBUTION OF HAIL WITH HEIGHT FOR ALL LOCATIONS (Ref. 34)

Height (Geometric) Above Surface (km)	Occurrence of Hail (percent of flights through thunderstorms)
2	0
3	3.5
5	10
6	4
8	3

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SECTION V. WIND

Wind is one of the most important atmospheric parameters used in the design of space vehicles. Because it has temporal and spatial variations, the representation of the data in a simple and concise form for design is extremely difficult. For these reasons, caution must be exercised in the employment of wind data to insure consistency with the physical interpretation relative to the specific design problem.

5.1 Surface Winds.

5.1.1 Definitions.

Surface winds as employed in this document are the winds measured in the atmosphere below a height of about 175 meters. These data are normally obtained with fixed measuring equipment, for example, cup-type or propeller-type anemometers. For purpose of determining appropriate load factors, the power law equation is used in computing the statistical envelope of wind speed versus height. The equation is (ref. 8):

$$V = V_1 \left(\frac{Z}{Z_1}\right)^p \qquad \text{Eq. (6)}$$

where:

V_1 = The wind speed at reference height Z_1

V = The wind speed at height Z

p = A nondimensional parameter determined empirically. It is a function of terrain, stability, wind speed, etc. For design purposes a value of 0.2 is employed when the three-meter height steady-state wind speed is 7 to 15 m sec^{-1}. A value of 0.14 is used for steady-state wind speeds from 22 m sec^{-1} to 30 m sec^{-1}.

Calm is defined as wind movement of less than 1 knot ($\sim$0.5 m sec^{-1}).

Quasi-Steady-State Wind is an average of the surface wind speed over a period of about two minutes. These are the basic climatalogical data normally recorded at measuring stations with fixed cup-type of propeller-type anemometers.

<u>Maximum Peak Surface Wind</u> is the highest surface wind expected including hurricane or severe thunderstorm conditions, but excluding tornadoes. In order to objectively determine a value of the expected maximum peak surface wind for the various heights, the power law, equation (6), was employed. The maximum peak wind corresponds to a mean return period (average number of years during which a single occurrence may be expected) of about 20 years (ref. 39). For certain design purposes the use of the same maximum peak wind (using the value at 61 m) over all heights may prove adequate.

<u>Squall Winds</u> are strong winds characterized by a sudden on-set, a duration of the order of minutes, and a sudden decrease in speed. The U. S. Weather Bureau reports a squall only if a wind speed of 16 knots, ($\sim$ 8 m sec^{-1}) or higher, is sustained for at least two minutes (thus distinguishing it from a gust). Squall winds are usually associated with thunderstorms.

<u>Hurricanes</u> (Typhoons) are severe tropical storms having winds of 64 knots, ($\sim$ 33 m sec^{-1}) or greater.

<u>Free Standing Winds</u> are the design surface winds which are applied when the vehicle is standing on the launch pad (with or without fuel) prior to launch and after any service structure or shelter has been removed. These design winds are higher because a large space vehicle may be free-standing for an extended period before launch. Normally the 99 or 99.9 percentile ground wind data are employed.

<u>Launch Winds</u> are the design surface winds which are applied for the launch of a vehicle. These wind criteria should not be exceeded at the time of launch or immediately subsequent to lift off. A hold may be required during the countdown if launch cannot be accomplished with the winds less than the specific design launch surface winds. Normally, the 95 or 99 percentile ground wind data are employed.

<u>Windiest Monthly Reference Period Concept</u>. The wind data for the various percentiles refer to the windiest monthly reference period. This means that the wind speed values were computed for each cumulative percentage frequency or percentile level for each of the twelve monthly periods represented by the available data, for example, all January's, all February's, etc. The maximum wind speed value for all the twelve monthly periods was selected for each percentile. This produced a wind speed value for a given percentile not exceeded by the observations for the windiest month. Obviously, the wind speed values for a given percentile envelope may come from different months, depending on the strength and persistence of the wind speeds for the various heights or altitudes.

Peak Wind is the wind speed based on a gust factor of 1.4 applied to the steady-state wind speed.

5.1.2 Wind Speed.

The data presented herein provide the basic wind speed envelope information used by most design organizations in determining load factors for use in test, free standing, launch, and lift-off studies to ensure satisfactory performance of the space vehicle. To establish vehicle design requirements, the surface winds are assumed to act normal to the longitudinal axis of the vehicle on the launch pad and to be from the worst direction. The quasi-steady-state, peak, and maximum peak wind speeds with reference to the windiest monthly reference period are given in Tables 5.1A through 5.6B (refs. 9, 28, 37, 39, and 52). Reference 52 should be consulted for additional surface wind speed and direction information for Cape Kennedy (Atlantic Missile Range). For specific design problems, data for other percentile levels and for various time exposure periods are available.

To establish these wind speed envelopes, the available statistical data (climatalogical) were reduced to a common reference height (3 meters) and values were determined for other heights by use of the power law equation (6) as given in the definitions (paragraph 5.1.1). This has provided a conservative estimate of the statistics for the more extreme heights based on recent data studies for certain locations. However, until a larger data sample is available, the values given herein are recommended as representative of the specific locations for design studies.

It is recognized that due to the complex nature of surface wind fluctuations as a function of terrain features, etc. the values given for the surface wind speed envelopes at the various locations are considered to be representative values only. They represent a common reference source for wind data from which appropriate load factors may be determined on a comparative basis by various design organizations. The tables provide only statistical design envelopes for given percentiles and are not meant to imply a perfect correlation of speeds over the heights shown.

The following tables encompass the various locations:

a. Tables 5.1A and 5.1B contain surface wind speed envelopes for the 99 and 99.9 percentiles respectively for Huntsville, Alabama.

b. Tables 5.2A and 5.2B contain surface wind speed envelopes for the 99 and 99.9 percentiles respectively for New Orleans, River Transportation, Gulf Transportation and Panama Canal Transportation.

c. Tables 5.3A and 5.3B contain surface wind speed envelopes for the 95 and 99 percentiles respectively for the Pacific Missile Range, West Coast Transportation and Sacramento, California.

d. Tables 5.4A, 5.4B, and 5.4C contain surface wind speed envelopes for the 95, 99, and 99.9 percentiles respectively for the Cape Kennedy (Atlantic Missile Range), Florida.

e. Tables 5.5A and 5.5B contain surface wind speed envelopes for the 95 and 99 percentiles respectively for Wallops Test Range, Virginia.

f. Tables 5.6A and 5.6B contain surface wind speed envelopes for the 95 and 99 percentiles respectively for the White Sands Missile Range, New Mexico.

TABLE 5.1A SURFACE WIND SPEED ENVELOPES 99 PERCENTILE FOR HUNTSVILLE

Height Above Ground		Quasi-Steady-State Wind		Peak Wind	
(m)	(ft)	(m sec^{-1})	(knots)	(m sec^{-1})	(knots)
3.0	10	10.3	20.1	14.5	28.1
9.1	30	12.9	25.0	18.0	35.0
18.3	60	14.8	28.8	20.7	40.3
30.5	100	16.4	31.9	23.0	44.7
61.0	200	18.8	36.6	26.3	51.2
91.4	300	20.4	39.7	28.6	55.6
121.9	400	21.6	42.0	30.2	58.8
152.4	500	22.6	44.0	31.7	61.6

TABLE 5.1B SURFACE WIND SPEED ENVELOPES 99.9 PERCENTILE FOR HUNTSVILLE

Height Above Ground		Quasi-Steady-State Wind		Peak Wind		Maximum Peak Wind	
(m)	(ft)	(m/sec)	(knots)	(m/sec)	(knots)	(m sec^{-1})	(knots)
3.0	10	12.4	24.1	17.3	33.7	32.2	62.5
9.1	30	15.4	30.0	21.6	42.0	37.4	72.8
18.3	60	17.7	34.5	24.8	48.3	41.3	80.3
30.5	100	19.7	38.2	27.5	53.5	44.3	86.2
61.0	200	22.6	43.9	31.6	61.5	48.9	95.0
91.4	300	24.5	47.6	34.3	66.6	51.7	100.6
121.9	400	25.9	50.4	36.3	70.6	53.9	104.7
152.4	500	27.1	52.7	38.0	73.8	55.6	108.0

TABLE 5.2A SURFACE WIND SPEED ENVELOPES 99 PERCENTILE FOR NEW ORLEANS, RIVER TRANSPORTATION, GULF TRANSPORTATION, AND PANAMA CANAL TRANSPORTATION

Height Above Ground		Quasi-Steady-State Wind		Peak Wind	
(m)	(ft)	(m sec^{-1})	(knots)	(m sec^{-1})	(knots)
3.0	10	9.5	18.5	13.3	25.9
9 1	30	11.8	23.0	16.6	32.2
18.3	60	13.6	26.5	19.1	37.1
30.5	100	15.1	29.3	21.1	41.0
61.0	200	17.3	33.7	24.3	47.2
91.4	300	18.8	36.5	26.3	51.1
121.9	400	19.9	38.7	27.9	54.2
152.4	500	20.8	40.5	29.2	56.7

TABLE 5.2B SURFACE WIND SPEED ENVELOPES 99.9 PERCENTILE FOR NEW ORLEANS, RIVER TRANSPORTATION, GULF TRANSPORTATION, AND PANAMA CANAL TRANSPORTATION

Height Above Ground		Quasi-Steady-State Wind		Peak Wind		Maximum Peak Wind	
(m)	(ft)	(m/sec)	(knots)	(m/sec)	(knots)	(m sec^{-1})	(knots)
3.0	10	13.4	26.1	18.8	36.5	37.6	73.0
9.1	30	16.7	32.5	23.4	45.5	43.8	85.1
18.3	60	19.2	37.4	27.0	52.4	48.3	93.8
30.5	100	21.3	41.4	29.8	58.0	51.8	100.7
61.0	200	24.4	47.5	34.2	66.5	57.1	111.0
91.4	300	26.5	51.6	37.1	72.2	60.4	117.5
121.9	400	28.1	54.6	39.3	76.4	62.9	122.3
152.4	500	29.4	57.1	41.1	79.9	64.9	126.2

TABLE 5.3A SURFACE WIND SPEED ENVELOPES 95 PERCENTILE FOR PACIFIC MISSILE RANGE, WEST COAST TRANSPORTATION, AND SACRAMENTO

Height Above Ground		Quasi-Steady-State Wind		Peak Wind	
(m)	(ft)	(m sec^{-1})	(knots)	(m sec^{-1})	(knots)
3.0	10	8.2	16.0	11.5	22.4
9.1	30	10.2	19.9	14.4	27.9
18.3	60	11.8	22.9	16.5	32.1
30.5	100	13.1	25.4	18.3	35.6
61.0	200	15.0	29.1	20.9	40.7
91.4	300	16.3	31.6	22.7	44.2
121.9	400	17.2	33.5	24.1	46.9
152.4	500	18.0	35.0	25.2	49.0

TABLE 5.3B SURFACE WIND SPEED ENVELOPES 99 PERCENTILE FOR PACIFIC MISSILE RANGE, WEST COAST TRANSPORTATION, AND SACRAMENTO

Height Above Ground		Quasi-Steady-State Wind		Peak Wind		Maximum Peak Wind	
(m)	(ft)	(m/sec)	(knots)	(m/sec)	(knots)	(m sec^{-1})	(knots)
3.0	10	10.3	20.0	14.4	28.0	30.5	59.2
9.1	30	12.8	24.9	18.0	34.9	35.5	69.0
18.3	60	14.7	28.6	20.6	40.0	39.1	76.0
30.5	100	16.3	31.7	22.8	44.4	42.0	81.7
61.0	200	18.7	36.4	26.2	51.0	46.3	90.0
91.4	300	20.3	39.5	28.4	55.3	49.0	95.3
121.9	400	21.5	41.8	30.1	58.5	51.0	99.2
152.4	500	22.5	43.7	31.5	61.2	52.6	102.3

TABLE 5.4A SURFACE WIND SPEED ENVELOPE 95 PERCENTILE* FOR ATLANTIC MISSILE RANGE

Height Above Ground		Quasi-Steady-State Wind		Peak Wind	
(m)	(ft)	(m sec^{-1})	(knots)	(m sec^{-1})	(knots)
3.0	10	7.2	14.0	10.1	19.6
9.1	30	9.0	17.4	12.6	24.4
18.3	60	10.3	20.0	14.4	28.0
30.5	100	11.4	22.2	16.0	31.1
61.0	200	13.1	25.5	18.4	35.7
91.4	300	14.2	27.6	19.9	38.6
121.9	400	15.1	29.3	21.1	41.0
152.4	500	15.7	30.6	22.0	42.8

* The 95 percentile winds are, in general, exceeded during heavy rain showers, thunderstorms in the area or over the site, squall lines, some frontal passages, strong pressure gradients, and hurricanes.

TABLE 5.4B SURFACE WIND SPEED ENVELOPE 99 PERCENTILE* FOR ATLANTIC MISSILE RANGE

Height Above Ground		Quasi-Steady-State Wind		Peak Wind	
(m)	(ft)	(m sec^{-1})	(knots)	(m sec^{-1})	(knots)
3.0	10	9.5	18.4	13.3	25.8
9.1	30	11.8	22.9	16.5	32.1
18.3	60	13.5	26.3	18.9	36.8
30.5	100	15.0	29.2	21.0	40.9
61.0	200	17.2	33.5	24.1	46.9
91.4	300	18.7	36.3	26.1	50.8
121.9	400	19.8	38.5	27.7	53.9
152.4	500	20.7	40.2	29.0	56.3

Note: The 99 percentile winds are, in general, exceeded during thunderstorms over the site, squall lines, occasional frontal passages and hurricanes.

TABLE 5.4C SURFACE WIND SPEED ENVELOPE 99.9 PERCENTILE** FOR ATLANTIC MISSILE RANGE

Height Above Ground		Quasi-Steady-State Wind		Peak Wind		Maximum Peak Wind	
(m)	(ft)	(m sec^{-1})	(knots)	(m sec^{-1})	(knots)	(m sec^{-1})	(knots)
3.0	10	11.8	23.0	16.6	32.2	36.5	71.0
9.1	30	14.8	28.7	20.7	40.2	42.6	82.8
18.3	60	16.9	32.9	23.7	46.1	46.9	91.2
30.5	100	18.8	36.5	26.3	51.1	50.4	98.0
61.0	200	21.6	41.9	30.2	58.7	55.6	108.0
91.4	300	23.4	45.4	32.7	63.6	58.8	114.3
121.9	400	24.7	48.1	34.6	67.3	61.2	119.0
152.4	500	25.9	50.3	36.2	70.4	63.2	122.8

** The 99.9 percentile winds are, in general, exceeded during heavy thunderstorms, severe squall lines, and hurricanes

TABLE 5.5A SURFACE WIND SPEED ENVELOPE 95 PERCENTILE FOR WALLOPS TEST RANGE

Height Above Ground		Quasi-Steady-State Wind		Peak Wind	
(m)	(ft)	(m sec^{-1})	(knots)	(m sec^{-1})	(knots)
3.0	10	8.9	17.3	12.4	24.2
9.1	30	11.1	21.6	15.5	30.2
18.3	60	12.8	24.8	17.8	34.7
30.5	100	14.1	27.4	19.8	38.4
61.0	200	16.2	31.5	22.7	44.1
91.4	300	17.6	34.2	24.6	47.9
121.9	400	18.6	36.2	26.1	50.7
152.4	500	19.4	37.8	27.2	52.9

TABLE 5.5B SURFACE WIND SPEED ENVELOPE 99 PERCENTILE FOR WALLOPS TEST RANGE

Height Above Ground		Quasi-Steady-State Wind		Peak Wind		Maximum Peak Wind	
(m)	(ft)	(m sec^{-1})	(knots)	(m sec^{-1})	(knots)	(m sec^{-1})	(knots)
3.0	10	11.2	21.8	15.7	30.5	40.6	78.9
9.1	30	14.0	27.2	19.6	38.1	47.3	92.0
18.3	60	16.0	31.2	22.5	43.7	52.2	101.4
30.5	100	17.8	34.6	24.9	48.4	56.0	108.9
61.0	200	20.4	39.7	28.6	55.6	61.7	120.0
91.4	300	22.1	43.0	31.0	60.2	65.3	127.0
121.9	400	23.5	45.6	32.8	63.8	68.0	132.2
152.4	500	24.5	47.7	34.4	66.8	70.2	136.4

TABLE 5.6A SURFACE WIND SPEED ENVELOPE 95 PERCENTILE FOR WHITE SANDS MISSILE RANGE

Height Above Ground		Quasi-Steady-State Wind		Peak Wind	
(m)	(ft)	(m sec^{-1})	(knots)	(m sec^{-1})	(knots)
3.0	10	9.7	18.8	13.5	26.3
9.1	30	12.0	23.4	16.9	32.8
18.3	60	13.8	26.9	19.4	37.7
30.5	100	15.3	29.8	21.5	41.7
61.0	200	17.6	34.2	24.6	47.9
91.4	300	19.1	37.1	26.7	51.9
121.9	400	20.2	39.3	28.3	55.0
152.4	500	21.1	41.1	29.6	57.5

TABLE 5.6B SURFACE WIND SPEED ENVELOPE 99 PERCENTILE FOR WHITE SANDS MISSILE RANGE

Height Above Ground		Quasi-Steady-State Wind		Peak Wind		Maximum Peak Wind	
(m)	(ft)	(m sec^{-1})	(knots)	(m sec^{-1})	(knots)	(m sec^{-1})	(knots)
3.0	10	12.4	24.1	17.3	33.7	37.2	72.3
9.1	30	15.4	30.0	21.6	42.0	43.4	84.3
18.3	60	17.7	34.5	24.8	48.3	47.8	92.9
30.5	100	19.7	38.2	27.5	53.5	51.3	99.8
61.0	200	22.6	43.9	31.6	61.5	56.6	110.0
91.4	300	24.5	47.6	34.3	66.6	59.9	116.4
121.9	400	25.9	50.4	36.3	70.6	62.3	121.2
152.4	500	27.1	52.7	38.0	73.8	64.4	125.1

5.1.3 Wind Shear and Gust.

Wind shear near the surface, for design purposes, is a shear which acts on a space vehicle free-standing on the pad or at time of lift-off. It may be an overturning moment if the center of gravity and the center of pressure are properly oriented. This shear is computed from the selected design percentile wind speed envelope by using the peak wind speed at the top of the vehicle and the quasi-steady-state wind speed at the base of the vehicle with respect to height of the base above the ground. For some space vehicles the base of the vehicle will be elevated some distance above the launch pad or ground level.

The gust shape and minimum period for the higher surface wind conditions given in the tables of Section 5.1.1 resemble a sharp wedge with linear increase to the peak wind for a minimum of two seconds and then linear decay to the steady state in two seconds. For the lower steady-state wind conditions the shape may be the same, have less amplitude, but with longer period. The gust factor is known to be a function of the steady state wind speed, time average of the wind speed, stability conditions, terrain features, and height. For purposes of this report a gust factor of 1.4 has been used to obtain the design peak wind speed.

Recently considerable interest has been exhibited in the use of random process techniques to define turbulent wind fluctuation for defining the dynamic structural response of vehicles free standing on a launch pad or other structures particularly vulnerable to wind loading. An example of these efforts are given in references 59 and 60. However, until additional data are available on gust spectra for the various locations, and specific techniques developed for design use of these data in structural response studies of large space vehicles, design gust spectra cannot be presented. Further information is available from the cognizant agency.

5.2 Inflight Winds.

5.2.1 Definitions.

Inflight Winds for purposes of this document are the winds above approximately 175 meters height.

Quasi-Steady-State Inflight Wind is an average of the vertical wind profile over approximately 600-meter altitude layers. These are the basic data normally recorded at measuring stations by use of rawinsonde balloons.

Wind Shear is the wind speed difference over some altitude interval divided by the interval. To have meaning for purposes of space vehicle design, the stated wind shear value must be associated with an altitude interval (scale-of-distance).

Discrete Gusts are represented by a buildup from a given quasi-steady-state wind speed and a subsequent decrease to a quasi-steady-state wind speed as a distinct feature in the vertical wind profile and may be individually identified. These gusts may appear as a quasi-square wave, one minus cosine or sinusoidal features on the wind profile.

Continuous Turbulence is characterized by the frequency of many gust components occurring in a random combination which in general will permit representation by power spectrum techniques.

Embedded Jet is a discrete gust type which occurs in the vertical wind profile over a rather narrow altitude layer (up to approximately 400-meters in depth). It is represented by a rather sharp wind buildup rate over a 25 to 50 meter altitude layer and maintains a speed greater than the average wind speed of the profile. The bluntness of the peak of the jet may vary from just a few meters to several hundred meters in altitude and have an amplitude in the order of 9 m sec^{-1} (17.4 knots).

5.2.2 Wind Speed.

Inflight wind speed profiles are used for design of the vehicle for flight through the atmosphere. The design inflight wind speeds may or may not be the same percentile as the surface wind speed. This depends upon the desired launch capability since the two design wind conditions are essentially independent statistical events.

Inflight wind information is basically of three types: (1) Sample of measured profiles, (2) statistical distributions, and (3) discrete or synthetic profiles. A detailed discussion of these three types of presentations may be found in reference 61. Each of these wind input types has certain limitations and the utility in design depends upon a number of considerations. Some of these are: a. Accuracy of basic measurements, b. Tolerable complexity of input, c. Economy practicality for design use, d. Representation of significant features of the wind profile, e. Statistical assumption versus physical representativeness, f. Ability to ensure control system and structural integrity, and g. Flexibility in design trade-off studies.

The oldest method of presentation of inflight design wind data involves the synthetic type of wind profile. Here various features of the wind profile, that is, wind speed, shear, gust, maximum wind layer thickness, etc. are described and design values established. In this document, synthetic wind profile type data are presented because this method of presentation appears to provide a reasonable approach for most design studies when properly employed. In addition, the concept of synthetic profiles is generally understood and employed by most aerospace design organizations. Therefore, the desirability of having a common set of design data criteria guidelines is evident. Descriptions of the wind input are generally available upon request for the various other design approaches given in references 35, 53 and 54 as may be approved by the cognizant design organization.

The source of the quasi-steady-state wind information for the data up to 30 km altitude is the upper air observations made by the standard AN/GMD 1A atmospheric sounding system. The data for Cape Kennedy, Florida and Santa Monica, California were serially completed (missing data inserted by interpolation, extrapolation, or use of data from nearby stations) by professional meteorologists. An analysis was performed to provide frequency distribution of quasi-steady state wind speeds and wind shear for each month as well as the annual period. References 35, 40, 62, and 67 contain additional data on the statistical distribution of winds for Cape Kennedy, Florida; Santa Monica, California; Wallops Test Range, Virginia; and El Paso, Texas (White Sands Missile Range, New Mexico) respectively. Additional data tabulations will be published as Range Reference Atmospheres by the Meteorological Working Group of the Inter-Range Instrumentation Group (IRIG). Contact the IRIG Secretarial, Range Commanders Conference, at White Sands Missile Range, New Mexico, for further information on availability of these documents (ref. 68). Information on interlevel correlations of wind are presented in NASA TN D-561 (ref. 38).

5.2.2.1 Inflight Wind Speed Profile Envelopes to 80 km Altitude. The idealized scalar wind speed profile envelopes presented herein include quasi-steady-state wind speeds to altitudes of 80 km. These winds are not expected to be exceeded by the given percentage of time based on the windiest monthly reference period concept (see definitions, Section 5.1.1). The wind data represent horizontal wind flow with reference to the surface of the earth. Vertical wind flow is negligible except for elastic body considerations of gust (turbulence) characteristics. These wind speeds are normally applied without regard to flight directions to establish initial vehicle design requirement. Specific percentile wind speed envelopes for design should be specified in the appropriate organizational space vehicle design criteria documentation. The data in the subsequent paragraphs provide for construction of idealized wind speed profile envelopes using linear segments to connect the given data points. The statistical data employed to establish the data points below 30 km altitude involved, in general, record of at least five years of twice-daily observations.

Generally, the larger space vehicles for use in comprehensive space research in operational programs are designed for wind speeds without regard to specific wind direction (scalar wind speeds). However, in special situations when a vehicle is always restricted to a given launch site and to rather narrow flight azimuths (within approximately 20 degrees), and for a specific configuration and mission, winds based on components (head, tail, left cross or right cross) may be used for design to produce selective launch capabilities. Usually for a given percentile, these component winds are of lesser magnitude than the scalar winds. They should not be employed in design unless specifically authorized by the cognizance design organization. Directional wind component frequency envelopes for Cape Kennedy, Florida are contained in reference 63. Similar data for the Pacific Missile Range as represented by inflight wind at Santa Monica, California are available in reference 71. Data for tilt program bias are also available.

The non-directional wind speed profile envelopes for the various locations are given in the following tables and figures:

a. Table 5.7 and Figure 5.1 contain the 50, 75, 90, 95, and 99 percentile scalar wind speeds profile envelopes for Cape Kennedy (Atlantic Missile Range).

b. Table 5.8 and Figure 5.2 contain the 50, 75, 90, 95, and 99 percentile scalar wind speed profile envelopes for Santa Monica, California (Pacific Missile Range).

c. Table 5.9 and Figure 5.3 contain the 95 and 99 percentile scalar wind speed profile envelopes for Wallops Test Range, Virginia.

d. Table 5.10 and Figure 5.4 contain the 95 and 99 percentile scalar wind speed profile envelopes for White Sands Missile Range, New Mexico.

It should be noted that the wind speeds for the altitudes between 30 and 80 km have been reduced from those previously presented in Marshall Technical Paper, MTP-AERO-63-8, January 28, 1963 (ref. 1). This reduction is due to the recent accumulation of data from the meteorological rocket networks at the various ranges (refs. 64 and 65) and a re-evaluation of the statistical data for purposes of design use.

TABLE 5.7 SCALAR WIND SPEED PROFILE ENVELOPES (QUASI-STEADY-STATE) FOR ATLANTIC MISSILE RANGE

Altitude (km)	Percentile, Wind Speed (m sec^{-1})				
	50	75	90	95	99
1	10	14	18	21	27.5
10	47	57	68	75	97
14	47	57	68	75	97
20	16	18	22	25	40
23	16	18	22	25	40
50	58	73	91	102	120
80	58	73	91	102	120

TABLE 5.8 SCALAR WIND SPEED PROFILE ENVELOPES (QUASI-STEADY-STATE) FOR PACIFIC MISSILE RANGE

Altitude (km)	Percentile, Wind Speed (m sec^{-1})				
	50	75	90	95	99
1	12.5	16	19.5	22.5	28
9					80
10		46	60	68	
11	34				
13	34	46	60	68	80
19	10	13	17	21	27
23	10	13	17	21	27
50	60	77	97	110	125
80	60	77	97	110	125

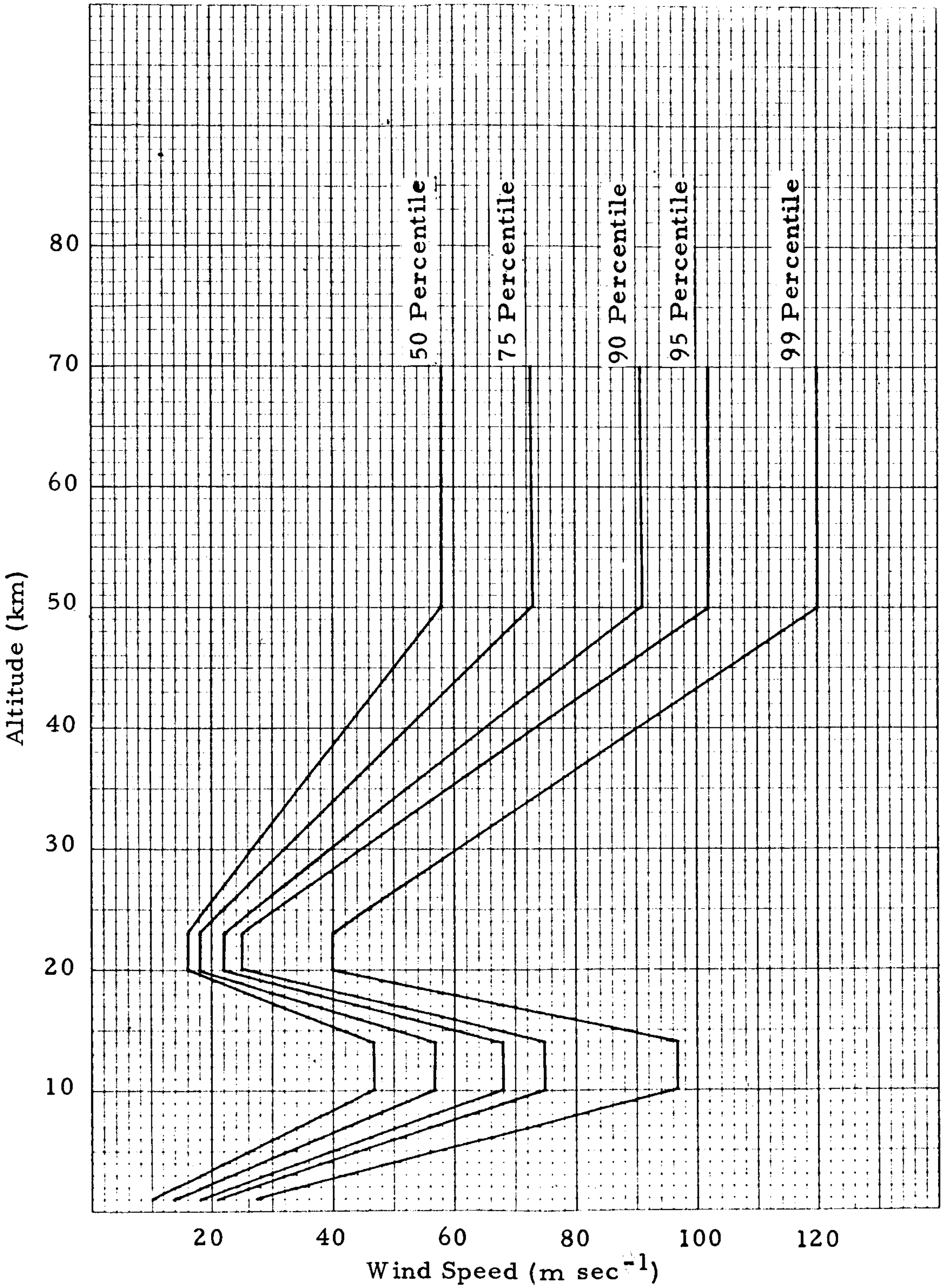

FIGURE 5.1 SCALAR WIND SPEED PROFILE ENVELOPES (QUASI-STEADY-STATE) FOR ATLANTIC MISSILE RANGE

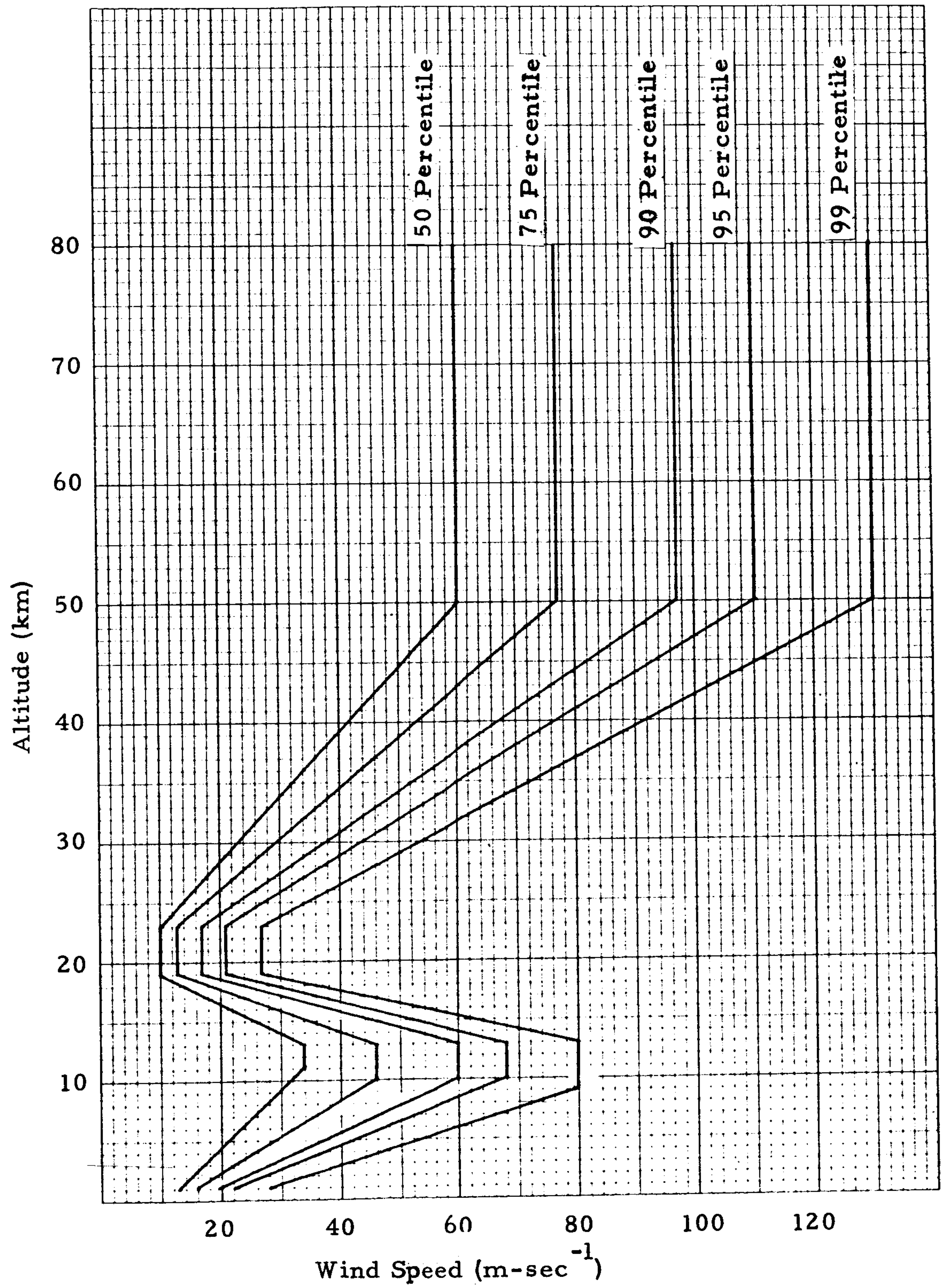

FIGURE 5.2 SCALAR WIND SPEED PROFILE ENVELOPES (QUASI-STEADY-STATE) FOR PACIFIC MISSILE RANGE

TABLE 5.9 SCALAR WIND SPEED PROFILE ENVELOPES (QUASI-STEADY-STATE) FOR WALLOPS TEST RANGE

Geometric Altitude (km)	Percentile 95 Wind Speed ($m\ sec^{-1}$)	Percentile 99 Wind Speed ($m\ sec^{-1}$)
1	24.5	30
9.5	75	88
10.5	75	88
20	27	33
23	27	33
50	120	140
80	120	140

TABLE 5.10 SCALAR WIND SPEED PROFILE ENVELOPES (QUASI-STEADY-STATE) FOR WHITE SANDS MISSILE RANGE

Geometric Altitude (km)	Percentile 95 Wind Speed ($m\ sec^{-1}$)	Percentile 99 Wind Speed ($m\ sec^{-1}$)
2.5	27.5	34.5
11	70	86
13	70	86
19	25	31
23	25	31
50	110	125
80	110	125

5.2.2.2 Wind Speed Profiles 80 to 400 km Altitude. The scalar wind speed profile envelope data presented in Table 5.11 provides information on the estimated maximum wind speeds which are expected to occur between 80 and 400 km altitude (refs. 50 and 66) at all locations. These data may be employed to determine the extent of the design problem, if any, that may exist for flight in this altitude region. Normally, the

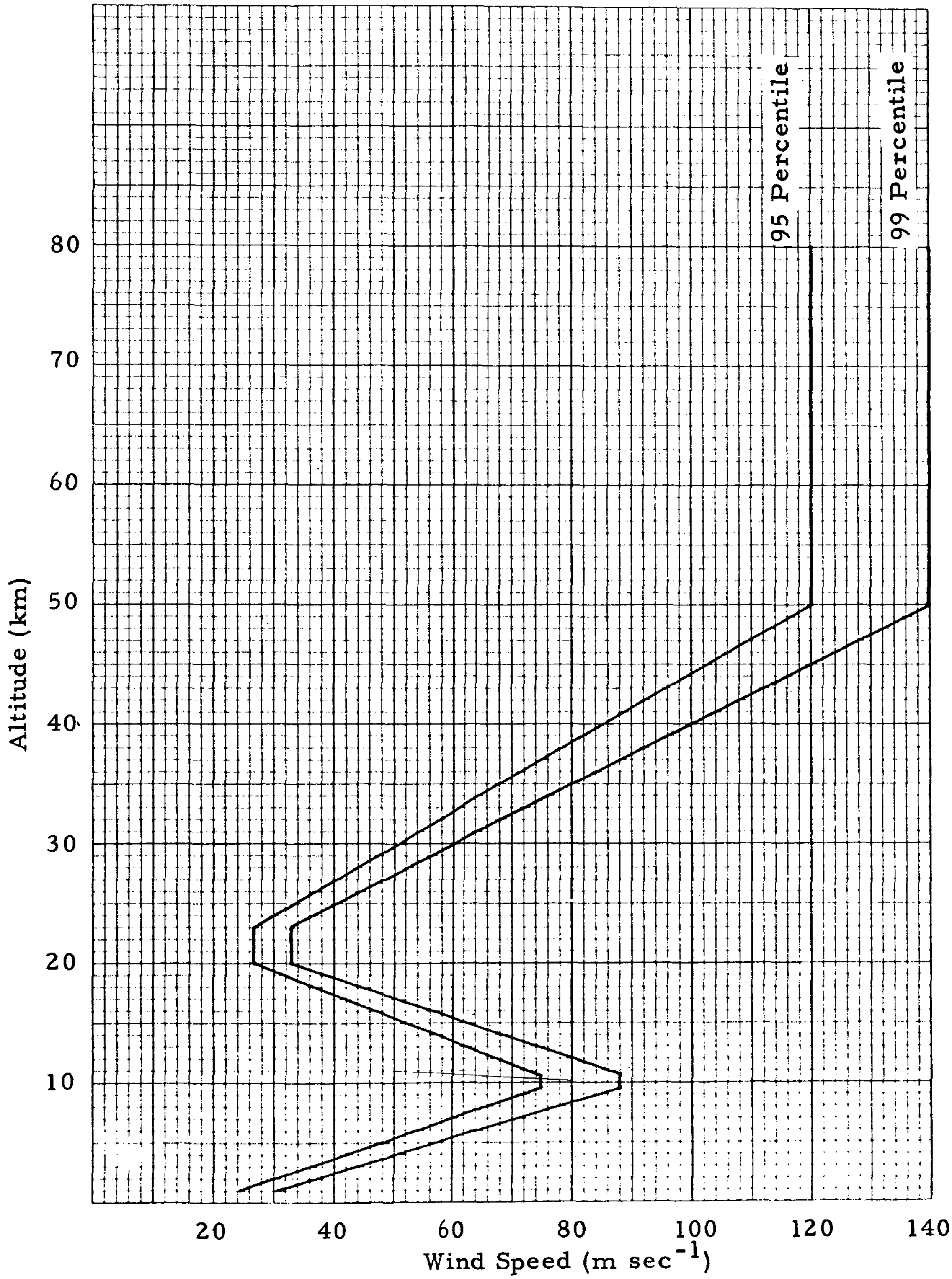

FIGURE 5.3 SCALAR WIND SPEED PROFILE ENVELOPES (QUASI-STEADY-STATE) FOR WALLOPS TEST RANGE

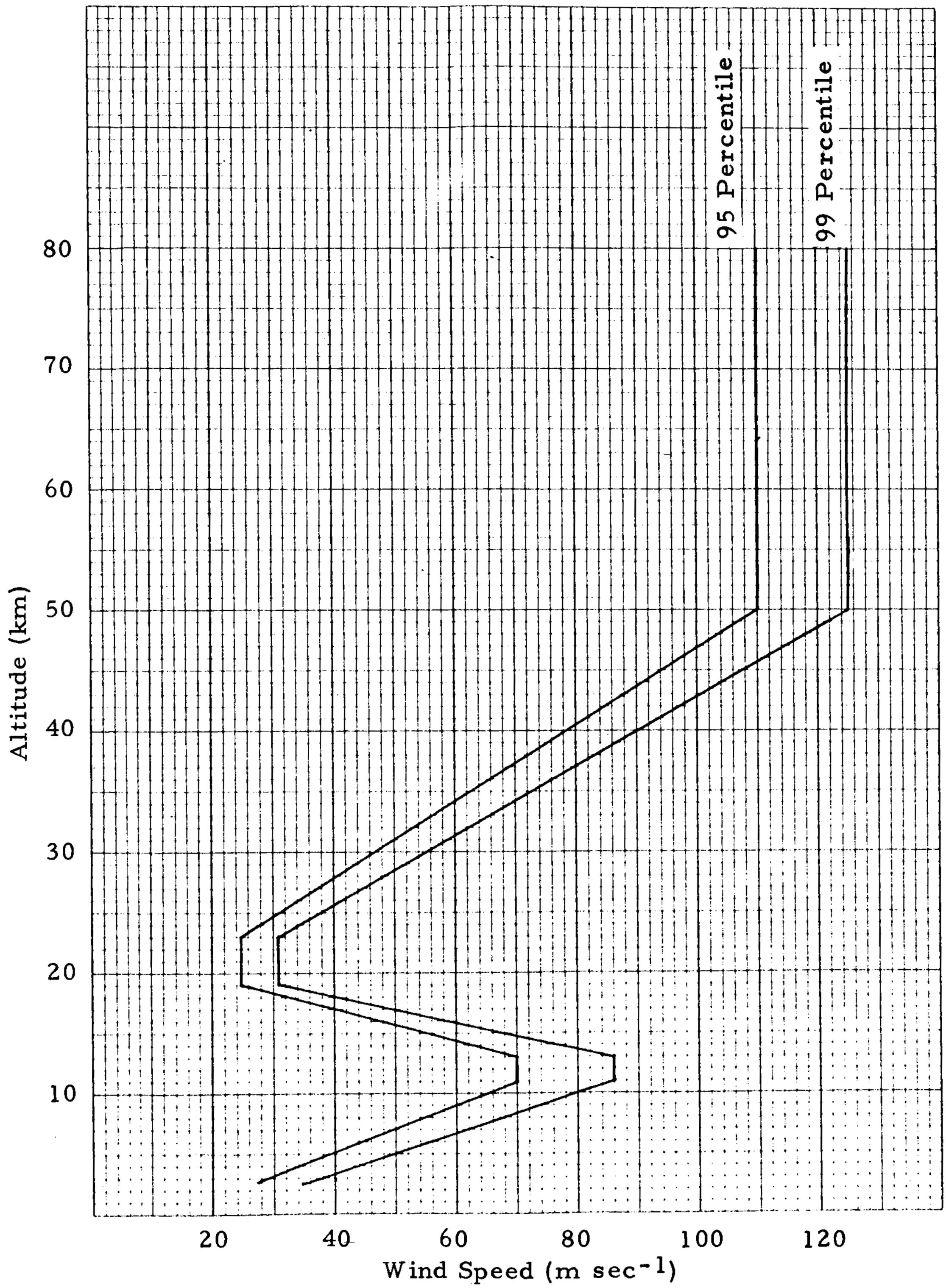

FIGURE 5.4 SCALAR WIND SPEED PROFILE ENVELOPES (QUASI-STEADY STATE) FOR WHITE SANDS MISSILE RANGE

dynamic pressure is considerably lower at these high altitudes and the control and structural problems for most space vehicle configurations, relative to wind influences, are at a minimum. Available data are not adequate to provide more detailed statistical analysis. Research is under way to better define these wind statistics.

TABLE 5.11 ESTIMATE OF MAXIMUM EXPECTED SCALAR WIND SPEED PROFILE ENVELOPE (QUASI-STEADY-STATE) FOR ALL LOCATIONS (ABOVE 80 km ALTITUDE)

Geometric Altitude (km)	Estimated Maximum Wind Speed (m sec^{-1})
80	200
200	350
300	400
400	500

5.2.2.3 Altitude Thickness of Strong Wind Layers. Most space vehicle structural and control system designs are established by specific wind profile features and their inter-relationships, such as wind buildup rate, quasi-steady-state wind speed, and gust characteristics. Treatment of the synthetic design wind profile after these features have been encountered may be by: (1) Producing a back-off rate based on the wind shear data, or (2) maintaining the wind speed profile for a realistic altitude thickness. Either technique is appropriate, depending upon the control system. It should be noted that the thickness of the strong wind layer in the wind profile and its bluntness depend upon the relationship of the measured profile to the jet stream core and the strength of the jet stream.

A recent analysis on the maximum thickness of strong wind layers for Cape Kennedy, Florida (Atlantic Missile Range), and Santa Monica, California (Pacific Missile Range), produced the data given in Tables 5.12 and 5.13. This analysis was based on the MSFC serially complete rawinsonde data records.

TABLE 5.12 MAXIMUM THICKNESS OF STRONG WIND LAYERS (6 YEARS RECORD) AT CAPE KENNEDY, FLORIDA

Quasi-Steady State Wind Speed (±5 m sec^{-1})	Maximum Thickness (km)	Altitude Range (km)
50	5	8.5 to 16.5
75	3	10.5 to 15.5
97	2	10.0 to 14.0

TABLE 5.13 MAXIMUM THICKNESS OF STRONG WIND LAYERS (5 YEARS RECORD) AT SANTA MONICA, CALIFORNIA

Quasi-Steady-State Wind Speed (±5 m sec^{-1})	Maximum Thickness (km)	Altitude Range (km)
50	5	8.0 to 16
75	3	9.5 to 14
97	-	—

5.2.3 Wind Shear and Wind Speed Change. The data in this section provide representative information on the wind shear and associated wind speed change for altitude layers (scale-of-distance) of 100 meters to 5,000 meters. The wind shear is the wind speed change over an altitude interval divided by the interval, The wind speed change or wind buildup rate is obtained by multiplying the wind shear by the appropriate scale-of-distance. Values of wind speed change or wind shear for a vehicle with other than a vertical flight path are found by multiplying the shear or wind speed change by the cosine of the flight path angle from the vertical.

The wind shear or synthetic wind profile buildup rate envelope is not meant to imply perfect correlation between the shears for the various scales-of-distance. Certain correlations do exist depending upon the scale-of-distance and the wind speed magnitudes considered. Research is being conducted to establish more quantitative data on these relationships. The wind shear data may be combined with the quasi-steady-state wind speed profile envelope data to establish synthetic wind profiles. One example of the synthetic wind profile construction is given in Figure 5.5. Additional information on the construction of synthetic wind buildup envelope profiles may be found in NASA TN D-1274 (ref. 36).

Wind shear statistics for the various locations vary somewhat, partly due to data sample size, accuracy of basic data, prevailing meteorological conditions, and orographic features. For the purpose of this document, one basic set of data on wind shear and wind buildup rates have been employed and are considered to be representative for all locations. Specific shear values for the various locations will be presented when sufficient data become available and analysis is published.

The following tables and figures provide the data on wind shear and wind buildup rates applicable for all locations.

a. Table 5.14 and Figure 5.6 provide idealized 99 percentile wind shear envelopes for various scale-of-distance corresponding to wind speeds in the 7 to 15 and 50 to 80 km altitude regions representative of all locations.

b. Table 5.15 and Figure 5.7 provide idealized 99 percentile wind speed change envelopes for the various scale-of-distance corresponding to wind speeds in the 7 to 15 km and 50 to 80 km altitude region representative of all locations.

5.2.4 Gust.

The collection of adequate data and definitions of gust characteristics associated with the vertical wind profile, and techniques for combining expressions of these characteristics with the various wind profile features as a design input, are still in the initial stages of development. Since this area is currently under development, the data presented must be considered tentative.

The quasi-steady-state inflight wind speed envelopes presented in Section 5.2.2 of this report do not contain an allowance for the gust or high frequency component of the wind profile. No completely suitable technique has been developed to quantitatively represent the high frequency component of the vertical wind profile for use in design studies. The use of discrete gust is still the major procedure used by various design organizations. Care should be exercised in deviating from these discrete gust characteristics until other concepts are more fully developed and tested. For purposes of design analysis, the

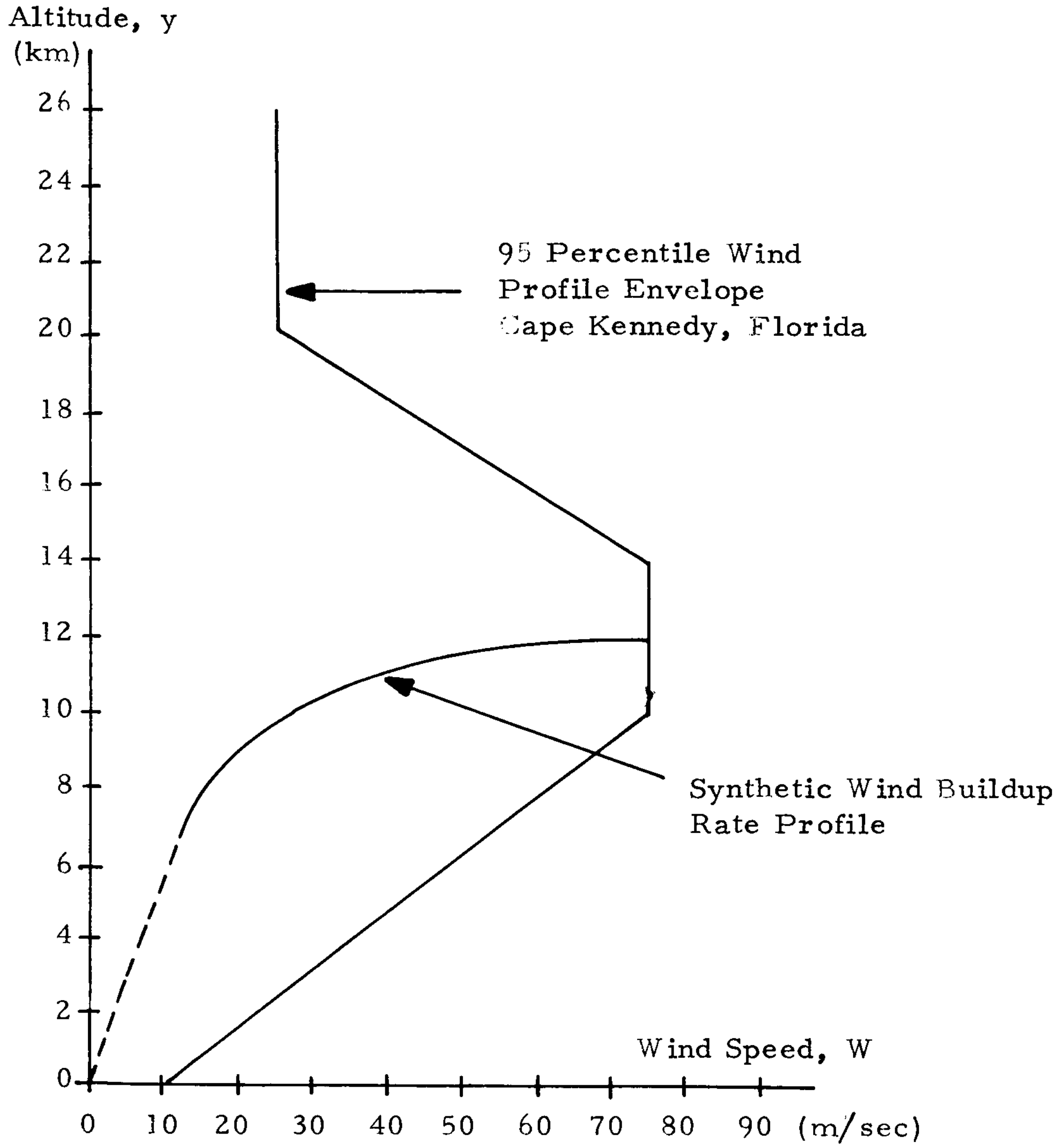

FIGURE 5.5 SYNTHETIC WIND PROFILE CONSTRUCTION BASED ON NINETY-NINE PERCENT WIND BUILDUP RATES ASSOCIATED WITH THE NINETY-FIVE PERCENTILE WIND SPEED PROFILE ENVELOPE AT 12 KM ALTITUDE

TABLE 5.14 IDEALIZED 99 PERCENTILE WIND SHEAR ENVELOPES FOR VARIOUS SCALE-OF-DISTANCE CORRESPONDING TO WIND SPEEDS IN THE 7 TO 15 KM AND 50 TO 80 KM ALTITUDE REGION FOR ALL LOCATIONS

Wind Speed in the 7 to 15 km Altitude Region	Scale-of-Distance (m)									
($m\ sec^{-1}$)	5000	4000	3000	2000	1000	800	600	400	200	100
$\geq$ 70	.0123	.0148	.0184	.0240	.0353	.0396	.0457	.0550	.0700	.0900
60	.0100	.0120	.0150	.0194	.0280	.0310	.0355	.0425	.0610	.0900
50	.0082	.0098	.0127	.0163	.0239	.0268	.0308	.0375	.0550	.0900
40	.0066	.0080	.0103	.0135	.0207	.0234	.0275	.0342	.0530	.0900
30	.0052	.0063	.0081	.0108	.0170	.0195	.0230	.0300	.0495	.0900
20	.0038	.0046	.0061	.0085	.0140	.0165	.0200	.0272	.0475	.0900
Wind Speed in the 50 to 80 km Altitude Region	**Scale-of-Distance (m)**									
($m\ sec^{-1}$)	5000	4000	3000	2000	1000	800	600	400	200	100
$\geq$ 100	.0160	.0190	.0234	.0310	.0450	.0489	.0540	.0610	.0750	.0900

Graphical presentation of this table is shown in Figure 5.6.

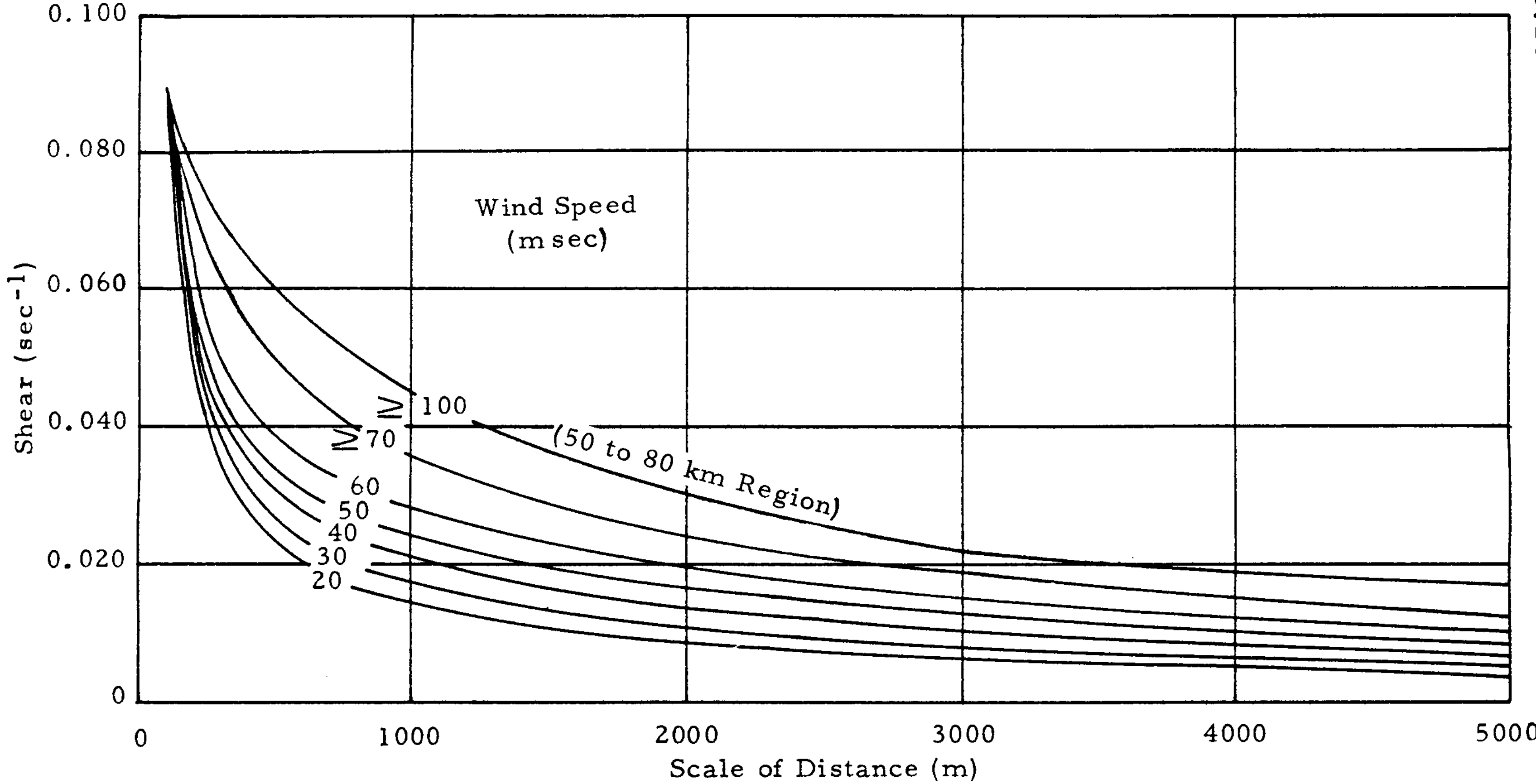

FIGURE 5.6 IDEALIZED 99 PERCENTILE WIND SHEAR (SEC^{-1}) ENVELOPES FOR VARIOUS SCALES-OF-DISTANCE CORRESPONDING TO WIND SPEEDS IN THE 7 TO 15 KM AND 50 TO 80 KM ALTITUDE REGION FOR ALL LOCATIONS

TABLE 5.15 IDEALIZED ENVELOPES OF 99 PERCENTILE WIND SPEED CHANGE FOR VARIOUS SCALE-OF-DISTANCE CORRESPONDING TO WIND SPEEDS IN THE 7 to 15 KM AND 50 TO 80 KM ALTITUDE REGION FOR ALL LOCATIONS

Wind Speed in the 7 to 15 km Altitude Region	Scale-of-Distance									
($m\ sec^{-1}$)	5000	4000	3000	2000	1000	800	600	400	200	100
≥ 70	61.5	59.2	55.2	48.0	35.3	31.7	27.4	22.0	14.0	9.0
60	50.0	48.1	45.0	38.7	28.0	24.8	21.3	17.0	12.2	9.0
50	41.0	39.4	38.0	32.7	23.9	21.4	18.5	15.0	11.0	9.0
40	33.0	32.0	31.0	27.0	20.7	18.7	16.5	13.7	10.6	9.0
30	26.0	25.2	24.2	21.7	17.0	15.6	13.9	12.0	9.9	9.0
20	19.0	18.6	18.3	17.0	14.0	13.2	12.0	10.9	9.5	9.0
Wind Speed in the 50 to 80 km Altitude Region	Scale-of-Distance									
($m\ sec^{-1}$)	5000	4000	3000	2000	1000	800	600	400	200	100
≥100	80.0	76.0	70.3	62.0	45.0	39.1	32.4	24.4	15.0	9.0

Graphical Presentation of this table is shown in Figure 5.7.

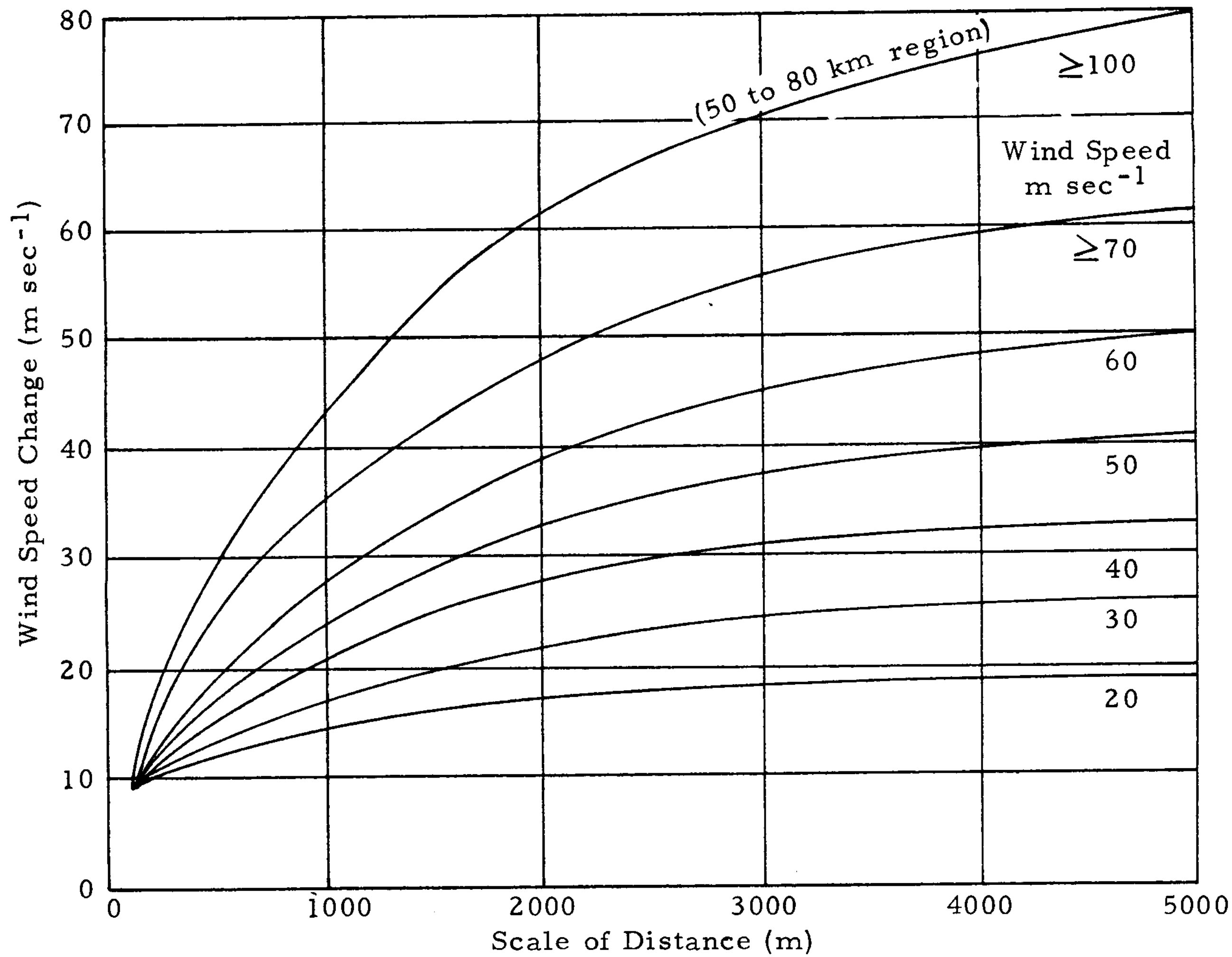

FIGURE 5.7 ENVELOPES OF 99 PERCENTILE WIND SPEED CHANGE (m sec^{-1}) FOR VARIOUS SCALES-OF-DISTANCE CORRESPONDING TO WIND SPEEDS IN THE 7 TO 15 KM AND 50 TO 80 KM ALTITUDE REGION FOR ALL LOCATIONS

vehicle response should not be based on all gust characteristics occurring simultaneously. Approved discrete or continuous turbulence characteristics should be employed which will provide for the greatest integrity of the launch vehicle control and/or structural design. Gusts are assumed for design purposes to act normal to the launch vehicle's longitudinal axis.

5.2.4.1 Discrete Gusts. Quasi-square-wave gusts have been identified and defined as having a maximum speed reaching a value of 9 m sec^{-1} greater than the quasi-steady-state wind speeds. These gusts are frequently referred to as embedded jets or singularities in the vertical wind profile. For mathematical convenience, these gusts may be employed as an extension to the wind buildup profile as noted in Figure 5.8. It should be understood that although this physical relationship is indicated, it has not been fully established. In addition, a discrete one minus cosine shape gust of similar amplitude has been observed in the vertical wind profile characteristics. This shape should also be considered in gust response studies.

Sinusoidal characteristics have been observed in certain high resolution vertical wind profile measurements. These gusts are not random in the sense of continuous turbulence as subsequently defined in this section. This characteristic of periodicity can be an important factor in elastic body reactions, fuel sloshing, flutter, structural dynamics, etc. These gusts have been identified and defined as being superimposed symmetrically on the quasi-steady-state wind speed profile. Efforts have been made to provide an analytical description in terms of wave length, peak to peak amplitude, and number of successive gusts for use in design studies. However, due to limited data sample, preliminary nature of the descriptions, and recognition of the fact that any such description is strongly related to the structural or control system dimulation procedures, no values will be stated as design criteria guidelines in this document.

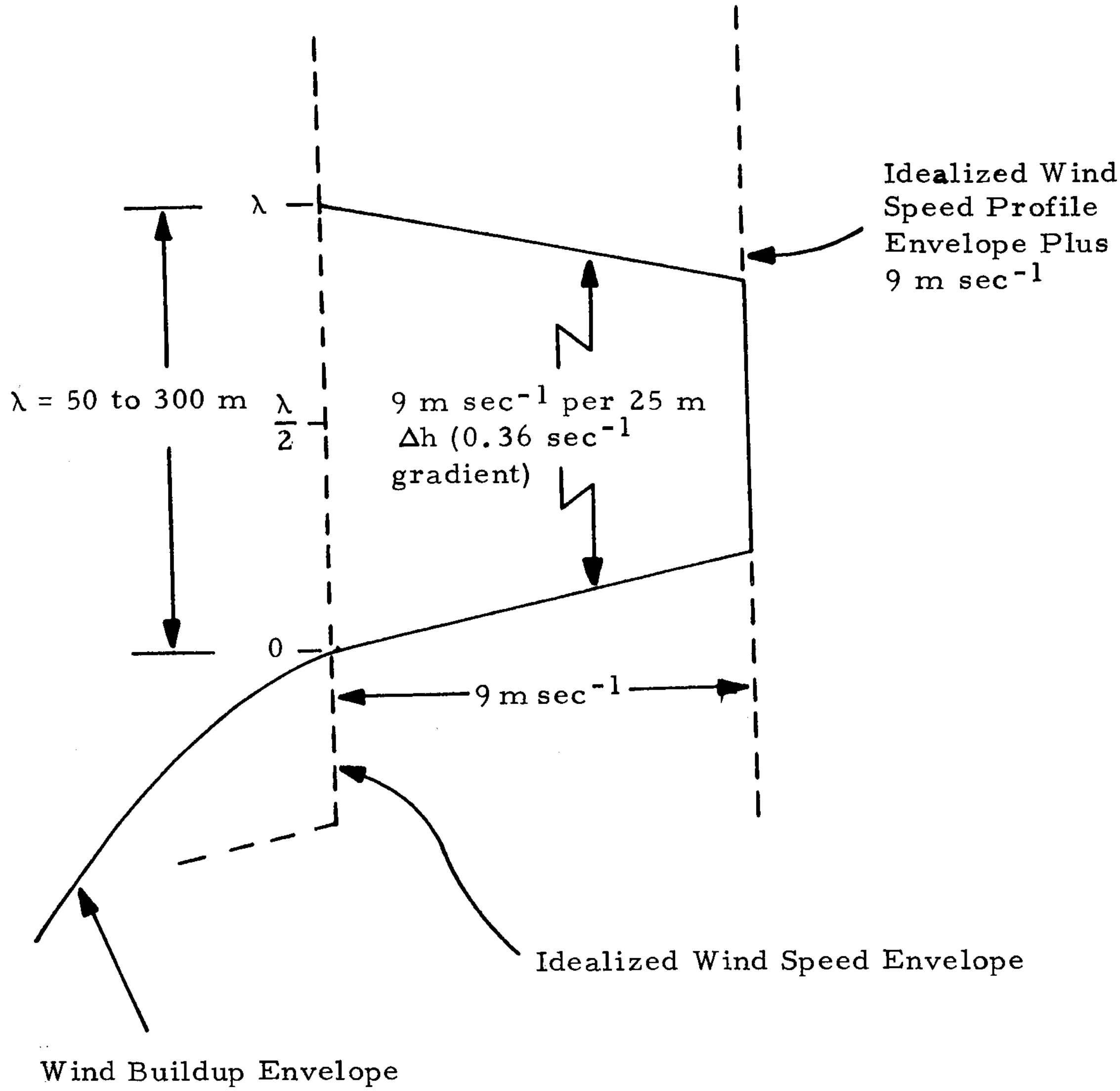

FIGURE 5.8 RELATIONSHIP BETWEEN ESTABLISHED GUSTS AND/OR EMBEDDED JET CHARACTERISTICS (QUASI-SQUARE WAVE SHAPE) AND THE IDEALIZED WIND SPEED (QUASI-STEADY-STATE) PROFILE ENVELOPE

5.2.4.2 Continuous Turbulence

Continuous turbulence is characterized by the presence of many frequency components occurring in a random combination. Efforts are currently in progress to describe statistically the turbulent content of the vertical wind profile. Until such time as adequate high resolution wind profile data are collected and analyzed, any description of continuous turbulence would be speculative and, therefore, has been omitted. Currently a spectral technique is under development to represent these turbulent features.

5.2.5 Combining Wind Parameters for Total Vehicle Response Calculations

From statistical relationships (for design purposes) between the various wind parameters, the steady-state wind speeds, gusts, and wind shears may be employed as follows for computing total vehicle responses:

$$R_T = R_{SS} + (R^2_G + R^2_{SH})^{1/2}$$

where R_T, R_{SS}, R_G, and R_{SH} are the total vehicle response and responses to the steady-state wind speed, gusts, and wind shears, respectively. This approach requires careful judgment by the designer due to the complexities involved in actual design employment. It does, however, from an environmental viewpoint avoid the simple addition of responses and the resulting conservative, but somewhat unrealistic, total response calculations for design purposes.

Techniques for combining the system response to discrete wind shear, steady-state winds, and gusts to produce reliable vehicle response for design purposes depend strongly upon the control mode employed in the design analysis and the organizational design philosophy The responsible government design organization should be contacted for the latest approved procedure.

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SECTION VI. ABRASION

6.1 Introduction.

Particles carried by wind will remove paint from exposed surfaces or scratch, abrade, or erode them, and pit transparent surfaces. When the particle wind velocities are low or moderate, damage can occur whenever the particle hardness is equal to or greater than the exposed surface. When an object is moving at high speeds with relation to the particles, erosion will occur even when the particles have a hardness less than the exposed surface. For example, raindrops may cause erosion if the relative velocities between the vehicle surface and raindrops are great enough (over 100 m sec^{-1} or 194 knots, ref. 41).

The penetration of sand and dust into moving parts (bearings, gears, etc.) can result in abnormal wear and failure. Large sand and dust particles may be suspended in the atmosphere during periods of high winds and low humidities (under 50 percent). Particles of dust less than 0.002 mm (0.000078 in.) in diameter are common at any time near or over land surfaces except shortly after precipitation. Particles larger than 0.002 mm (0.000078 in.) will settle out rapidly unless wind or other forces are present to keep the particles suspended. Small particles in the atmosphere over the sea will consist almost entirely of salt.

Particle hardness in this section is expressed according to Mohs' hardness scale, which is based on the relative hardness of representative minerals as listed in Table 6.1 (ref. 5).

TABLE 6.1 MOHS' SCALE-OF-HARDNESS FOR MINERALS

Mohs' Relative Hardness	Mineral	Mohs' Relative Hardness	Mineral
1	Talc	6	Orthoclase
2	Gypsum	7	Quartz
3	Calcite	8	Topaz
4	Fluorite	9	Corundum
5	Apatite	10	Diamond

6.2 Sand and Dust at Surface.

The presence of sand and dust can be expected at all areas of interest. The extreme values expected are as follows:

6.2.1 Size of Particles.

a. Sand particles will be between 0.080 mm (0.031 in.) and 1.0 mm (0.039 in.) in diameter. At least 90 percent of the particles will be between 0.080 mm (0.031 in.) and 0.30 mm (0.012 in.) in diameter.

b. Dust particles will be between 0.0001 mm (0.0000039 in.) and 0.080 mm (0.0031 in.) in diameter. At least 90 percent of these particles will be between 0.0001 mm (0.0000039 in.) and 0.002 mm (0.000079 in.) in diameter.

6.2.2 Hardness and Shape.

More than 50 percent of the sand and dust particles will be composed of angular quartz or harder material, with a hardness of 7 to 8.

6.2.3 Number and Distribution of Particles.

a. Sand. For a steady-state wind speed of 10 m sec^{-1} (19 knots) at 3 m (9.9 ft) above surface and relative humidity of 30 percent or less, there will be 0.02 g cm^{-3} (1.2 lb ft^{-3}) of sand suspended in the atmosphere during a sand storm. Under these conditions, 10 percent of the sand grains will be between 0.02 m (0.079 ft) and 1.0 m (3.3 ft) above the ground surface, with the remaining 90 percent below 0.02 m (0.079 ft), unless disturbed by a vehicle moving through the storm.

b. Dust. For a steady-state wind speed of 10 m sec^{-1} (19 knots) at 3 m (9.9 ft) above surface, and relative humidity of 30 percent or less, there will be 6×10^{-9} g cm^{-3} (3.7×10^{-7} lb ft^{-3}) of dust suspended in the atmosphere. Distribution will be uniform to 200 m (656 ft) above the ground.

6.3 Sand and Dust at Altitude.

Only small particles (less than 0.002 mm (0.000079 in.)) will be in the atmosphere above 400 m (1312 ft) in the areas of interest.

During actual flight, the vehicle should pass through the region of maximum dust in such a short time that little or no abrasion can be expected.

6.4 Snow and Hail at Surface.

Snow and hail can cause abrasion at Huntsville, River Transportation, New Orleans, Wallops Test Range, and White Sands Missile Range areas. Extreme values expected with reference to abrasion are as follows:

6.4.1 Snow Particles.

Snow particles will have a hardness of 1.5 to 4 (ref. 42) and a diameter of 1.0 mm (0.039 in.) to 5.0 mm (0.20 in.). Steady-state wind speed of 10 m sec^{-1} (19 knots) at a minimum air temperature of -17.8° C (0° F) should be considered for design calculations. At New Orleans a minimum air temperature of -9.4° C (15° F) should be used.

Hail particles will have a hardness of 1.5 to 4 and a diameter of 5.0 mm (0.20 in.) or greater. Steady-state wind speed of 10 m sec^{-1} (19 knots) at an air temperature of 10.0° C (50° F) should be considered for design calculations.

6.5 Snow and Hail at Altitude.

Snow and hail particles will have higher hardness values at higher altitudes. The approximate hardness of snow and hail particles in reference to temperature is given in Table 6.2. (See paragraph 4.4.2 remarks.)

TABLE 6.2 HARDNESS OF HAIL AND SNOW FOR ALL LOCATIONS

Temperature		Relative Hardness (Mohs' Scale)
(°C)	(°F)	
0	32.0	2
-20	- 4.0	3
-40	- 40.0	4
-60	- 76.0	5
-80	-112.0	6

Although the flight time of a vehicle through a cloud layer would be extremely short, if the cloud layer contains a large concentration of moderate sized hailstones (25 mm (1 in.) or larger) at temperatures below -20.0°C (-4°F), considerable damage could be expected (especially to antennas and other protrusions) because of the kinetic energy of the hailstone at impact. Tests have shown a definite relationship between the damage to aluminum aircraft wing sections and the velocity of various sized hailstones. Equal dents (sufficient to require repair) of 1 mm (0.039 in.) in 75 S-T aluminum resulted from the following impacts (ref. 30):

a. A 19-mm (0.75 in.) ice sphere at 190 m sec^{-1} (369 knots).

b. A 32-mm (1.25 in.) ice sphere at 130 m sec^{-1} (253 knots).

c. A 48-mm (1.88 in.) ice sphere at 90 m sec^{-1} (175 knots).

6.6 Raindrops.

With the advent of high-speed aircraft a new phenomenon has been encountered in the erosion of paint coatings, of structural plastic components, and even of metallic parts by the impingement of raindrops on surfaces. The damage may be severe enough to affect the performance of a missile. Tests conducted by the British Ministry of Aviation (ref. 41) have resulted in a table of rates of erosion for various materials and coatings. These materials and coatings were tested at speeds of 220 m sec^{-1} (428 knots). Sufficient data are not available to present any specific extreme values for use in design, but results of the tests indicate that materials used should be carefully considered and weather conditions evaluated prior to launch.

SECTION VII. ATMOSPHERIC PRESSURE

7.1 Definition.

Atmospheric pressure (also called barometric pressure) is the pressure exerted as a consequence of gravitational attraction upon the column of air of unit cross section lying directly above the area in question. It is expressed as force per unit area.

7.2 Pressure at Surface.

The total variation of pressure from day to day is relatively small. Rapid but relatively small variations occur as the result of the passage of frontal systems. Surface pressure extremes for various locations are given in Table 7.1.

7.3 Pressure Change.

a. A gradual rise or fall in pressure of 3 mb (0.04 lb in.$^{-2}$) and then a return to original pressure can be expected over a 24-hour period.

b. A maximum pressure change (frontal passage change) of 6 mb (0.09 lb in.$^{-2}$) (rise or fall) can be expected within a 1-hour period at all localities.

7.4 Pressure at Altitude.

Atmospheric pressure extremes for all locations are given in Table 7.2.

TABLE 7.1 SURFACE PRESSURE EXTREMES

Area	Pressure				Elevation (from mean sea level) of Equivalent Station with Standard Atmospheric Conditions			
	Units	Maximum	Mean	Minimum	Units	Maximum	Mean	Minimum
Huntsville	newton m^{-2}	101600	98800	94800	m	- 21	202	532
	mb	1016	988	948				
	lb in. $^{-2}$	14.7	14.3	13.7	ft	- 69	663	1745
River Transportation	newton m^{-2}	104100	100000	90000*	m	-215	106	948
	mb	1041	1000	900*				
	lb in. $^{-2}$	15.1	14.5	13.1*	ft	-705	348	3110
New Orleans, Atlantic Missile Range, Gulf Transportation, Panama Canal Transportation, and Wallops Test Range	newton m^{-2}	104100	101330	90000*	m	-215	0	948
	mb	1041	1013.3	900*				
	lb in. $^{-2}$	15.1	14.7	13.1*	ft	-705	0	3110
West Coast Transportation, Pacific Missile Range, and Sacramento	newton m^{-2}	104100	101330	98500	m	-215	0	225
	mb	1041	1013.3	985				
	lb in. $^{-2}$	15.1	14.7	14.3	ft	-705	0	738
White Sands Missile Range	newton m^{-2}	90000	88000	81000	m	948	1216	1400
	mb	900	880	810				
	lb in. $^{-2}$	13.1	12.8	11.7	ft	3110	3989	4598

* During hurricane conditions

TABLE 7.2 ATMOSPHERIC PRESSURE-HEIGHT EXTREMES FOR ALL LOCATIONS

Altitude**		Pressure					
		Maximum		Median		Minimum	
(km)	(ft)	(mb)	(lb in. $^{-2}$)	(mb)	(lb in. $^{-2}$)	(mb)	(lb in. $^{-2}$)
0	0	(Use values in Table 7.1 for surface pressure for each station)					
3	9,800	730	10.6	714	10.4	680	9.86
6	19,700	510	7.40	490	7.11	460	6.67
10	32,800	295	4.28	283	4.10	255	3.70
15	49,200	135	1.96	129	1.87	118	1.71
20	65,600	60	8.7×10^{-1}	56	8.1×10^{-1}	51	7.4×10^{-1}
25	82,000	30	4.4×10^{-1}	28	4.1×10^{-1}	22	3.2×10^{-1}
30	98,400	12.5	1.8×10^{-1}	11.7	1.7×10^{-1}	11.2	1.6×10^{-1}
40	131,000	2.9	4.2×10^{-2}	3.0	4.4×10^{-2}	2.5	3.6×10^{-2}
50*ƒ	164,000	1.2	1.7×10^{-2}	8.5×10^{-1}	1.2×10^{-2}	1.5×10^{-1}	2.2×10^{-3}
75*ƒ	246,000	7.5×10^{-2}	1.1×10^{-3}	2.5×10^{-2}	3.6×10^{-4}	2.5×10^{-4}	3.6×10^{-6}
100*ƒ	328,000	2.5×10^{-3}	3.6×10^{-5}	3.2×10^{-4}	4.5×10^{-6}	7.2×10^{-6}	1.0×10^{-7}
300*#	984,000	9.9×10^{-7}	1.4×10^{-8}	2.0×10^{-7}	2.9×10^{-9}	2.5×10^{-8}	3.6×10^{-10}
500*#	1,640,000	8.4×10^{-8}	1.2×10^{-9}	1.2×10^{-8}	1.7×10^{-10}	1.2×10^{-9}	1.7×10^{-11}
700*#	2,300,000	1.7×10^{-8}	2.5×10^{-10}	1.3×10^{-9}	1.9×10^{-11}	5.9×10^{-11}	8.6×10^{-13}

* Median values from references 2 and 21.
ƒ Maximum and minimum values estimated.
Maximum and minimum values from reference 51.
** Geometric altitude above mean sea level.

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SECTION VIII. ATMOSPHERIC DENSITY

8.1 Definition.

Density is the ratio of the mass of a substance to its volume. (It also is defined as the reciprocal of specific volume.) Density is usually expressed in grams per cubic centimeter or in kilograms per cubic meter.

8.2 Atmospheric Density at Surface.

The variation of the density of the atmosphere at the surface from the average for any one station, and between the areas of interest, is small and should have no important effect on preflight operations.

8.3 Atmospheric Density at Altitude.

The density of the atmosphere changes rapidly with height, being only one-half that of the surface at 7 km altitude. The extreme values of density with altitude for all locations are given in Table 8.1. The density varies with latitude, being higher for the same altitudes at 45 degrees N latitude than at locations with lower latitudes (ref. 57). For this reason density values given in Table 8.1 below 100 km vary from those given in the U. S. Standard Atmosphere, 1962 (ref. 2). Information on the variation of density to altitudes of 120 km may be found in NASA TN D-612 (ref. 43).

TABLE 8.1 DENSITY-HEIGHT EXTREMES FOR ALL LOCATIONS

Altitude**		Density					
		Maximum		Median		Minimum	
(km)	(ft)	(g cm^{-3})	(lb ft^{-3})	(g cm^{-3})	(lb ft^{-3})	(g cm^{-3})	(lb ft^{-3})
0	0	1.27×10^{-3}	7.93×10^{-2}	1.18×10^{-3}	7.36×10^{-2}	1.10×10^{-3}	6.87×10^{-2}
3	9,800	9.7×10^{-4}	6.05×10^{-2}	8.9×10^{-4}	5.56×10^{-2}	8.6×10^{-4}	5.37×10^{-2}
6	19,700	7.1×10^{-4}	4.43×10^{-2}	6.5×10^{-4}	4.06×10^{-2}	6.2×10^{-4}	3.87×10^{-2}
10	32,800	4.55×10^{-4}	2.84×10^{-2}	4.22×10^{-4}	2.63×10^{-2}	4.05×10^{-4}	2.53×10^{-2}
15	49,200	2.40×10^{-4}	1.50×10^{-2}	2.19×10^{-4}	1.37×10^{-2}	2.05×10^{-4}	1.28×10^{-2}
20	65,600	1.02×10^{-4}	6.37×10^{-3}	9.3×10^{-5}	5.81×10^{-3}	8.9×10^{-5}	5.56×10^{-3}
25	82,000	4.4×10^{-5}	2.75×10^{-3}	4.0×10^{-5}	2.50×10^{-3}	3.8×10^{-5}	2.37×10^{-3}
30	98,400	2.0×10^{-5}	1.25×10^{-3}	1.8×10^{-5}	1.12×10^{-3}	1.7×10^{-5}	1.06×10^{-4}
40*†	131,000	5.3×10^{-6}	3.35×10^{-4}	4.12×10^{-6}	2.57×10^{-4}	2.31×10^{-6}	1.44×10^{-4}
50*†	164,000	1.45×10^{-6}	9.05×10^{-5}	1.10×10^{-6}	6.9×10^{-5}	7.2×10^{-7}	4.49×10^{-5}
75*†	246,000	6.1×10^{-8}	3.81×10^{-6}	4.3×10^{-6}	2.7×10^{-6}	2.0×10^{-8}	1.25×10^{-6}
100*†	328,000	6.0×10^{-10}	3.75×10^{-8}	5.2×10^{-10}	3.2×10^{-8}	1.4×10^{-10}	8.7×10^{-9}
300*#	984,000	1.4×10^{-13}	8.7×10^{-12}	3.8×10^{-14}	2.4×10^{-12}	5.4×10^{-15}	3.4×10^{-13}
500*#	1,640,000	9.4×10^{-15}	5.9×10^{-13}	1.7×10^{-15}	1.1×10^{-13}	2.1×10^{-16}	1.3×10^{-14}
700*#	2,300,000	1.8×10^{-15}	1.1×10^{-13}	1.7×10^{-16}	1.1×10^{-14}	9.6×10^{-18}	6.0×10^{-16}

\# Maximum and minimum values for reference 51.

* Median values from references 2 and 21.

† Maximum and minimum values from reference 43.

** Geometric altitude above mean sea level.

SECTION IX. ATMOSPHERIC ELECTRICITY

9.1 Thunderstorm Electricity.

Vehicles not adequately protected can be damaged by (1) direct lightning strike, (2) induced current from a lightning stroke on a nearby object and the flow of current through the object, or (3) a charge induced by nearby charged clouds. Protection to the vehicle is accomplished by ensuring that all metallic sections are connected electrically (bonded) so that the current flow from a lightning stroke is conducted over the skin without any gaps where sparking would occur or current would be carried inside. MIL-B-5087 A (ASG), 30 July 1954, and later amendments (ref. 44) give requirements for electrical bonding. Objects on the ground, such as buildings, may be protected by a system of lightning rods and wires over the outside to carry the lightning stroke to the ground. See reference 72 for the lightning protection plan for Saturn Launch Complex 39. If lightning should strike a space vehicle ready for test or flight, or a large metallic object nearby such as the test stand or gantry, a complete checkout will be required of all electronic components and moving parts in the vehicle. Potential gradient recorders which will give warning of dangerous conditions in the local area are currently being produced commercially. If potential gradient is a critical item, the use of a unit to monitor potential gradient conditions during test periods shall be considered.

9.1.1 Direct Lightning Stroke and Induced Current.

A direct lightning strike is possible at all locations of interest, but the frequency of such an occurrence is different at the various locations, as given in Table 9.1 (refs. 31 and 72).

Lightning strokes have the following characteristics at all the areas covered by this document (refs. 45, 46 and 47):

a. An average peak current of 10,000 amperes can be expected. The peak current flow is reached 6 microseconds after start of stroke, with a fall to one-half the peak value in 24 microseconds. A total stroke charge of 25 coulombs is transmitted to the earth with 90 percent of the current flow, after the initiation of the first stroke, at less than 1000 amperes.

TABLE 9.1 PERCENTAGE FREQUENCY-OF-OCCURRENCE OF THUNDERSTORMS

Location	Mean Number of Days Per Year for Thunderstorms	Monthly Distribution (percent of annual)											
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
Huntsville	70	1	3	6	8	11	19	22	18	9	1	1	1
River Transportation and New Orleans	75	3	3	5	5	8	16	21	20	10	3	3	3
Gulf Transportation	90	1	1	4	2	9	18	24	23	12	4	1	1
Atlantic Missile Range	75	1	2	5	5	9	19	18	20	14	5	1	1
Panama Canal Transportation	100	1	1	4	2	9	18	24	23	12	4	1	1
Pacific Missile Range and West Coast Transportation	6	9	11	19	13	7	4	3	7	8	8	3	8
Sacramento	4	6	16	12	15	9	6	3	3	10	12	5	3
Wallops Test Range	41	1	2	5	7	13	19	24	18	7	2	1	1
White Sands Missile Range	35	1	1	3	6	14	19	24	18	9	3	1	1

b. The maximum peak current will not be greater than 100,000 amperes 90 percent of the time. This peak current flow is reached in 10 microseconds after start of the stroke, and the current then falls to one-half the peak value in 20 microseconds. A total stroke charge of 100 coulombs is transmitted to the earth, with 95 percent of the current flow, after the initiation of the first stroke, at less than 5000 amperes.

9.1.2 Induced Charge from Nearby Charged Clouds.

In many cases, current can be induced in equipment from the normal atmospheric potential charge or from the additional charges which develop in a thunderstorm before lightning discharges occur. The average potential gradient at the earth's surface is about 100 volts cm^{-1}, on a clear day. The potential required for a lightning flash during a thunderstorm, however, has been estimated to be as high as 5000 volts cm^{-1}. Because of the potential gradient, severe shocks can occur from the charge induced along a metal cable on a captive balloon. Similarly induced charges on television antennas have exploded fine wire coils in television sets. Such equipment damage can be prevented by installing lightning arresters with air gaps small enough to discharge the current before it discharges through the equipment.

9.1.3 Radio Interference.

Whenever an electrical charge produces a spark between two points, electromagnetic radiation is emitted. This discharge is not limited to a narrow band of frequencies but covers most of the electromagnetic radiation spectrum with various intensities. Most static heard in radio reception is related to electrical discharges, with lightning strokes contributing a large percentage of the interference. This interference from lightning strokes is propagated through the atmosphere in accordance with laws valid for ordinary radio transmission and may travel for great distances. With the transmission of interference from lightning strokes over great distances, certain frequencies become prominent, with 30 kc being the major frequency. For this reason, the interference to telemetering and guidance need be considered only when thunderstorms are occurring within 100 km (60 miles) of the space vehicle site. Prediction of such weather should be obtainable from the weather forecast personnel.

9.1.4 Coronal Discharges from Remote Lightning Strokes.

The electrical discharge discussed in paragraph 1.3 may propagate sufficient electromagnetic radiation to produce a charge and a subsequent coronal discharge within the space vehicle. Such a discharge may be severe, when lightning storms are within about 16 km (10 miles) of the launch pad, and are due to electric field reversals.

9.2 Static Electricity.

A static electric charge can result from motion of an object through air containing dust or snow particles, or by wind-borne dust or snow particles striking the object. This charge builds up until a potential is reached sufficiently high to bridge an air gap and so permit the charge to be carried to the ground. A discharge of potential will then occur, and may cause the ignition of explosive gases or interference in radio communications. This type of discharge, which occurs more frequently during periods of low humidities, is best prevented by grounding all metallic parts.

Static electric discharges can be expected at all geographical areas of concern.

SECTION X. SALT SPRAY

Wind moving over breaking sea waves will pick up small droplets of salt water. These droplets are small enough to remain suspended in the air. Some will evaporate and leave tiny particles of salt in the air. When these droplets and particles accumulate on metallic surfaces and dry, a film of salt is left on the metal. When the relative humidity is near saturation, or when light rain or drizzle occurs, the salt on the metal will absorb water and form a highly conductive solution. Corrosion by electrolytic action can result when two dissimilar metals are involved, and corrosion of a single metal can occur when the solution can react chemically.

Methods have been devised to simulate the effects of salt spray in the laboratory. The following procedures have been taken from Federal Test Method Standard No. 150, Method 811, or MIL-STD-810, Method 509 (ref. 25):

a. A salt solution is formed under the following conditions:

(1) Five percent sodium chloride in distilled water.

(2) pH between 6.5 and 7.2 and specific gravity from 1.027 to 1.041 when measured at a temperature between 33.3° and 36.1°C (92° and 97°F).

b. An air temperature of 35.0°C (95°F) is maintained in the test chamber.

c. The salt solution is atomized and applied so that 0.5 to 3.0 milliliters (0.015 to 0.10 fluid ounces) of solution will collect over an 80-square-centimeter (12.4 square in.) horizontal area in 1 hour.

d. The time of exposure of the test material is 168 hours. Such a test is assumed to be equal to about 1 year of natural exposure to salt spray.

e. Increasing the salt concentration will not accelerate the test.

Protection from salt spray will be required in the following areas:

(1) New Orleans

(2) Gulf Transportation

(3) Atlantic Missile Range

(4) Panama Canal Transportation

(5) Pacific Missile Range

(6) West Coast Transportation

(7) Sacramento

(8) Wallops Test Range

SECTION XI. FUNGI AND BACTERIA

Fungi (including mold) and bacteria have the highest rate of growth at temperatures between 20.0°C (68°F) and 37.7°C (100°F) and relative humidities between 75 and 95 percent (refs. 23 and 48). Fungi and bacteria secrete enzymes and acids during their growth. These secretions can destroy most organic substances and many of their derivatives. Typical materials which will support growth of fungi and bacteria and are damaged by them if not properly protected are: cotton, wood, linen, leather, paper, cork, hair, felt, lens-coating material, paints, and metals. The four groups of fungi used in the fungus-resistance tests for equipment are as follows:

Group	Organism	American Type Culture Collection Number
I	Chaetomium globosum	6205
	Myrothecium verrucaria	9095
II	Memeniella echinata	9597
	Aspergillus niger	6275
III	Aspergillus flavus	10836
	Aspergillus terreus	10690
IV	Penicillium citrinum	9849
	Penicillium ochrochloron	9112

A suspension of mixed spores made from one species of fungus from each group is sprayed on the equipment being tested in a test chamber. The equipment is then left for 28 days in the test chamber at a temperature of 30° ± 2°C (86° ± 3.6°F) and relative humidity of 95 ± 5 percent.

Equipment is usually protected from fungi and bacteria by incorporating a fungicide-bactericide in the material, by a fungicide-bactericide spray, or by reducing the relative humidity to a degree where growth will not take place. A unique method used in the Canal Zone to protect delicate, expensive bearings in equipment was to maintain a pressure (with dry air or nitrogen) slightly above the outside atmosphere (few millibars) within the working parts of the equipment, thus preventing fungi from entering equipment.

Proper fungus- and bacteria-proofing measures are required at the following areas:

(1) River Transportation

(2) New Orleans

(3) Gulf Transportation

(4) Panama Canal Transportation

(5) Atlantic Missile Range

SECTION XII. OZONE

Ozone, although considered one of the rare atmospheric gases, needs consideration in design because of its chemical reactivity (oxidation) with organic materials, especially rubber, which becomes hard and brittle under tension. Ozone, in high concentration, is explosive and poisonous. It may be formed in high concentrations by short wave length ultraviolet light (below 2537A°), or by the arcing or discharge of electrical currents. A motor or generator with arcing brushes is an excellent source of ozone. The natural ozone concentration at the earth's surface is normally less than 3 parts per hundred million (phm), except during periods of intense smog, where it may exceed 5 phm. Ozone concentration increases with altitude, with the maximum concentration being at about 30 km (98,000 ft).

Maximum values of natural atmospheric ozone, for purposes of design studies, are as follows: (a) Surface, at all areas, a maximum concentration of three phm except during smog, when the maximum will be six phm, and (b) maximum concentration, with altitude, is given in Table 12.1 (ref. 49).

TABLE 12.1 DISTRIBUTION OF MAXIMUM VALUES OF OZONE CONCENTRATION WITH ALTITUDE FOR ALL LOCATIONS

Geometric Altitude (km)	(ft)	Ozone (parts per hundred million)	Ozone Concentration (cm/km)
SRF*	SRF*	5	0.005
9.1	30,000	30	0.010
15.2	50,000	200	0.030
21.3	70,000	700	0.040
27.4	90,000	1100	0.024
33.5	110,000	1100	0.009
39.6	130,000	600	0.002
45.7	150,000	400	0.0005

* SRF - Surface

SECTION XIII. ATMOSPHERIC COMPOSITION

13.1 Composition.

The earth's atmosphere is made up of a number of gases in different relative amounts. Near sea level and up to about 90 km, the amount of these atmospheric gases in clean dry air is practically constant. Four of these gases, nitrogen, oxygen, argon, and carbon dioxide, make up 99.99 percent by volume of the atmosphere. Two gases, ozone and water vapor, change in relative amounts, but the total amount of these two is very small compared to the amount of the other gases.

The atmospheric composition shown in Table 13.1 can be considered valid up to 90 km geometric altitude.

Above 90 km, mainly because of molecular dissociation and diffusive separation, the composition changes from that shown in Table 13.1.

Data on atmospheric composition above 90 km are to be determined.

13.2 Molecular Weight.

The atmospheric composition shown in Table 13.1 gives a molecular weight of 28.9644 for dry air (ref. 2). This value of molecular weight can be used as constant up to 90 km, and is equivalent to the value 28.966 on the basis of a molecular weight of 16 for oxygen.

The molecular weight of the atmosphere with relation to height is shown in Table 13.2.

TABLE 13.1 NORMAL ATMOSPHERIC COMPOSITION FOR CLEAN, DRY AIR NEAR SEA LEVEL AT ALL LOCATIONS (VALID TO 90 KILOMETERS GEOMETRIC ALTITUDE)

Gas	Percent by Volume	Percent by Weight*
Nitrogen (N_2)	78.084	75.520
Oxygen (O_2)	20.9476	23.142
Argon (Ar)	0.934	1.288
Carbon dioxide (CO_2)	0.0314	0.048
Neon (Ne)	1.818×10^{-3}	1.27×10^{-3}
Helium (He)	5.24×10^{-4}	7.24×10^{-5}
Krypton (Kr)	1.14×10^{-4}	3.30×10^{-4}
Xenon (Xe)	8.7×10^{-6}	3.9×10^{-5}
Hydrogen (H_2)	5×10^{-5}	3×10^{-6}
Methane (CH_4)	2×10^{-4}	1×10^{-4}
Nitrous Oxide (N_2O)	5×10^{-5}	8×10^{-5}
Ozone (O_3) summer	0 to 7×10^{-6}	0 to 1.1×10^{-5}
winter	0 to 2×10^{-6}	0 to 3×10^{-6}
Sulfur dioxide (SO_2)	0 to 1×10^{-4}	0 to 2×10^{-4}
Nitrogen dioxide (NO_2)	0 to 2×10^{-6}	0 to 3×10^{-6}
Ammonia (NH_3)	0 to trace	0 to trace
Carbon monoxide (CO)	0 to trace	0 to trace
Iodine (I_2)	0 to 1×10^{-6}	0 to 9×10^{-6}

* On basis of Carbon 12 isotope scale for which $C^{12} = 12.000$, as adopted by the International Union of Pure and Applied Chemistry meeting, Montreal, in 1961.

TABLE 13.2 MOLECULAR WEIGHT OF THE ATMOSPHERE FOR ALL LOCATIONS

Geometric Altitude (km)	(ft)	Molecular Weight
SRF*	SRF*	28.9644
to	to	
90	295,000	28.9644
100	328,000	28.88
300	984,000	22.66
500	1,640,000	17.94
700	2,300,000	16.17

*SRF - Surface

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TERRESTRIAL ENVIRONMENT (CLIMATIC) CRITERIA GUIDELINES FOR USE IN SPACE VEHICLE DEVELOPMENT, 1964 REVISION

by

Glenn E. Daniels, Editor

The information in this report has been reviewed for security classification. Review of any information concerning Department of Defense or Atomic Energy Commission programs has been made by the MSFC Security Classification Office. This report, in its entirety, has been determined to be unclassified.

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TERRESTRIAL ENVIRONMENT
(CLIMATIC) CRITERIA GUIDELINES
FOR USE IN SPACE VEHICLE
DEVELOPMENT, 1964 REVISION

By

Glenn E. Daniels, Editor

March 13, 1964

Page vi, Figure 2.1, delete word "Exposed."

Page vii, Table 2.9, the word "Exposed" should read "Extreme."

Page 5.1, next to last line, the word "of" should be "or."

Page 5.4, the following should be inserted after par. f:

"The 'Maximum Peak Wind' values given in the following tables are not 99 or 99.9 percentile wind values but maximum peak surface wind values as defined on page 5.2."

Page 5.11, last line, third paragraph of Section 5.1.3, should read: "is available from the cognizant design agency."

Page 5.13, ninth line, first paragraph should read "... references 36, 53 and 54..."

Page 5.16, the vertical lines of the five curves should be extended to 80 km at the same speeds as at 70 km.

Page 5.29, next to last line, the word "dimulation" should be "simulation."

Page 6.2, par. 6.2.1.a, first line and third line, "0.80 mm (0.031 in.)" should read "0.80 mm (0.0031 in.)."

Page 6.3, at end of first paragraph under par. 6.4.1, insert "6.4.2 Hail Particles."

Page 7.3, at the bottom of the table, the statement "*Median values from references 2 and 21," should read, "*Median values from references 3 and 21."

Page 8.2, at the bottom of the table, the statement, "*Median values from references 2 and 21, "should read, "*Median values from references 3 and 21."

Page 15.7, reference 62, "NASA TN D-1249," should be "NASA TN D-1249."